BEACH EROSION CONTROL REPORT ON COOPERATIVE STUDY OF PLUM ISLAND MASSACHUSETTS

CORPS OF ENGINEERS, U. S. ARMY
OFFICE OF THE DIVISION ENGINEER
NEW ENGLAND DIVISION, BOSTON, MASS.

AUGUST 29, 1952

ARMY-NED-BOSTON

BEACH EROSION CONTROL REPORT ON COOPERATIVE STUDY OF PLUM ISLAND, MASS.

TABLE OF CONTENTS

REQUEST FOR RECORDS

For use of this form, see AR 340-18-1; the proponent agency is TAGCEN.

DATE OF REQUEST: 5/11/76

TO BE COMPLETED BY CUSTODIAN

DATE RECORDS MUST BE RETURNED: 5/18/76

1. OFFICE OF RECORD

a. CUSTODIAN AND ADDRESS

KHA 146

b. RECORDS REQUESTED *(Give file classification, subject, date, and other identifying information. If records of personnel are requested, give name (LAST NAME FIRST), grade, Social Security Account Number, type of file requested, and purpose for which records are to be used.)*

BEACH EROSION CONTROL REPORT OF PLUM ISLAND

R-2

c. ESTIMATED NUMBER OF DAYS RECORDS ARE NEEDED:

2. REQUESTER

a. NAME, OFFICE ADDRESS AND TELEPHONE NUMBER OF PERSON REQUESTING RECORDS.

BILL COLEMAN

COASTAL DEV 113 N

ALL REQUESTS MUST BE SIGNED BY AN INDIVIDUAL AUTHORIZED TO WITHDRAW THE RECORDS REQUESTED.

b. SIGNATURE OF AUTHORIZED PERSON

3. SEARCHER'S REPORT

	a. RECORDS ATTACHED FOR DELIVERY TO ADDRESS IN ITEM 2
	b. RECORDS CURRENTLY ON LOAN *(See Item 3d)*
	c. UNABLE TO IDENTIFY RECORDS

d. IF ITEM 3b IS CHECKED, GIVE NAME OF PERSON TO WHOM RECORDS ARE LOANED, OFFICE ADDRESS, TELEPHONE NO., AND DATE LOANED

e. DATE SEARCHED

f. SIGNATURE OR INITIALS OF SEARCHER

4. FOLLOW-UP ACTION

DATE OF TRACER OR CALL	REMARKS	SUSPENSE DATE EXTENDED TO	CLERK'S INITIALS

5. RECEIPT IS ACKNOWLEDGED OF ☐ CLASSIFIED ☐ UNCLASSIFIED FILE IDENTIFIED ABOVE

DATE	TYPED NAME AND GRADE	SIGNATURE

DA FORM 1 MAY 70 543 REPLACES DA FORM 543, 1 JAN 56, WHICH WILL BE USED.

COPY 2 - SUSPENSE

APPENDICES

PLATES

CORPS OF ENGINEERS, U. S. ARMY
OFFICE OF THE DIVISION ENGINEER
NEW ENGLAND DIVISION
857 COMMONWEALTH AVENUE
BOSTON 15, MASS.

NEDVG August 29, 1952

SUBJECT: Beach Erosion Control Report on Cooperative Study of Plum Island, Massachusetts.

TO: The Chief of Engineers, Department of the Army, Washington 25, D. C.

SYLLABUS

The purpose of the study is to devise effective means of preventing further erosion by waves and currents of that portion of Plum Island, Massachusetts, located in the City of Newburyport and the Town of Newbury.

The Division Engineer finds that erosion of the beach and sand dunes and damages to and destruction of cottages have occurred as a result of wave attack during storms, that the zone of erosion has shifted during recent years along the entire seaward shore of the northern end of Plum Island which is developed for cottage use and south thereof, that the present most severe problem area is located along the narrowest portion of the island opposite "The Basin" and that continuation of this erosion, in addition to losses to the beach and cottages, can result in breaching of the island at its narrowest point and isolation of the extensive development located to the north.

The Division Engineer concludes that the most suitable method of protection consists of, (1) direct placement of sand fill to widen the beach fronting cottages and dunes in the problem area, and (2) raising the elevation of the inshore portion of the south jetty at the Merrimack River entrance as may be required to act as a barrier to northward drifting and loss of beach material into the Merrimack River.

The shore to be protected is almost entirely privately-owned and therefore not eligible to receive Federal assistance in the first cost of construction of protective works in accordance with existing law. The Division Engineer consequently recommends that no Federal project be adopted for Plum Island at this time.

BEACH EROSION CONTROL REPORT ON COOPERATIVE STUDY OF PLUM ISLAND, MASSACHUSETTS

I. GENERAL

1. Authority. - This study was made by the Corps of Engineers, United States Army, in cooperation with the Department of Public Works of the Commonwealth of Massachusetts under authority of Section 2 of the River and Harbor Act approved July 3, 1930 as amended and supplemented. Formal application therefor dated May 8, 1952 was approved by the Chief of Engineers on June 13, 1952.

2. Purpose. - The purpose of the study as stated in the application is to devise effective means of preventing further erosion by waves and currents of the portion of the shore of Plum Island, Massachusetts, located in the City of Newburyport and the Town of Newbury.

3. Prior Reports. - No prior beach erosion control report has been made for this location. Beach erosion control studies north of Plum Island were completed by the Beach Erosion Board for Salisbury Beach, Massachusetts in 1941, and for Seabrook and Hampton Beaches, New Hampshire in 1932. Studies were continued on Hampton Beach by the District Engineer up to 1942. Reports of the effects of the jetties at the mouth of the Merrimack River on the adjacent shore line were prepared by the District Engineer during 1938 and 1939. A geologic report, Bulletin No. 7, "The Geology of the Coast of Northeastern Massachusetts" was prepared by United States Geological Survey in cooperation with the Massachusetts Department of Public Works in 1941. This latter report discusses the geology of the area, formation of Plum Island, shore processes, recent changes and probable future trends. Information pertinent to the study is available in the Annual Reports of the Chief of Engineers under Newburyport Harbor, Massachusetts. The Annual Reports contain information concerning construction of the jetties at the mouth of the

Merrimack River, and changes associated with their construction. Data from the above reports are contained in Appendix A, "Geology," Appendix B, "Composition of Beaches," Appendix G, "Existing Shore Structures," and Appendix H, "Prior Reports."

4. Location. - The study area is located on Plum Island, Massachusetts, in the City of Newburyport and the Town of Newbury. Its northern end is at the mouth of the Merrimack River about 3.7 miles south of the Massachusetts-New Hampshire boundary. The study area extends about 4.7 miles south of the river mouth to the boundary between the Towns of Newbury and Rowley. The remainder of Plum Island within the Towns of Rowley and Ipswich extends an additional 3.6 miles southward to Plum Island Sound. The entire island faces the Atlantic Ocean to the east and is separated from the mainland on the west by Plum Island River and extensive marshes.

5. Population. - The 1950 population of the City of Newburyport was 14,111, and of the Town of Newbury was 1994. The permanent population in the developed section at the north end of Plum Island is approximately 100 families. It is estimated that the population reaches or exceeds 3500 people during the summer season.

6. Description. - The seaward shore line of Plum Island is about 8 miles in length. The island is a sandy barrier bar largely covered with dunes which in places attain a height in excess of 50 feet above mean sea level. The width of this sand bar south of "The Basin," a body of water projecting southward from the estuary of the Merrimack River, varies between one-tenth and four tenths of a mile, averaging about one-fourth of a mile. The bar is separated from Plum Island River to the west by a width of marsh generally greater than that of the bar. The width of the bar at its narrowest point east of "The Basin" is about 350 feet. The bar increases in width northward from this narrow point to its maximum width of six-tenths of a mile at the Merrimack River. Development is concentrated in the north end

of the island which lies within the limits of the City of Newburyport and the Town of Newbury. This development consists of about 900 cottages, a church, a clam chlorinating plant, a number of food shops, restaurants, fishing tackle shops, boat rental businesses and a United States Coast Guard Station. The remainder of the island to the south, with minor exceptions, is a wild life sanctuary under Federal control. There is another United States Coast Guard Station in this southern portion of the island in the Town of Ipswich. The only overland access to the island exists from the City of Newburyport over Plum Island Turnpike, a causeway over the marshes. This turnpike connects with Northern Boulevard, the only surfaced road on Plum Island and the only road serving the development at the north end of the island. The area under study is shown on U.S.C.&G.S. Charts 331 and 1206 and the Newburyport East Quadrangle of the United States Geological Survey.

II. STATEMENT OF THE PROBLEM

7. Problem. - The most urgent problem exists at the north end of the island in the Town of Newbury. The shore involved is located at the narrowest portion of the island opposite "The Basin." The problem consists of recession of the shore through erosion of the beach and sand dunes caused by wave attack during storms. This recession has reportedly reduced the width of lots seaward of Northern Boulevard from 190 - 260 feet in 1920 to 40 - 50 feet in 1950. Approximately 50 feet of this recession resulted from three storms during 1950. Storm attack has damaged or destroyed cottages located on the sand dunes in this area and has necessitated the repeated moving of buildings landward. At the present time, cottages are located close to Northern Boulevard and there is no space left for further movement. It is estimated that damages to cottages in this area during two storms which occurred in September and November 1950 amounted to $100,000. Continued recession of the shore can result in breaching of the island and

isolation of its northern end. This would isolate about 600 cottages, a number of business establishments and the United States Coast Guard Station near the mouth of the Merrimack River. Erosion of the shore and dunes, and damages similar to those described above formerly occurred to the most northerly cottages along the seaward shore of Plum Island adjacent to the United States Coast Guard Reservation. These damages occurred during the period 1939-1941. In more recent years, this northerly area has reportedly benefited from accretion of the shore. Erosion of the shore and minor storm damages reportedly occurred to the most southerly cottages south of Plum Island Turnpike along the seaward shore of Plum Island during February 1952. Damages in this area have not yet assumed serious proportions although concern is felt about the possibility of continued shore recession. No problem exists at present along the greater part of the island south of the cottage development. This portion of the island is used as a wild life sanctuary and does not possess any development close to the shore.

III. FACTORS PERTINENT TO THE PROBLEM

8. Physical Characteristics. - Plum Island is a sandy barrier bar with a narrow sand beach backed by a wide area of dunes. In the problem area opposite "The Basin," the beach has a very steep profile with a foreshore slope of about 1 on 10. Waves break practically on the shore line and the normal uprush of waves over the beach berm in places reaches and erodes the dunes. The western half of the island, behind the dunes, is made up of extensive marshes.

9. The Merrimack River enters the Atlantic Ocean at the northern extremity of Plum Island. The river has a length of about 120 miles, drains about 5000 square miles, is tidal and improved for navigation for 20 miles inland. The average river discharge as measured at Lowell, Massachusetts, is about 7000 cubic feet per second and the maximum discharge is 173,000 cubic feet per second. The river entrance is fixed by two rubble mound jetties.

10. Geology. - The shore line of Plum Island is one of submergence of the land with respect to the level of the sea. The island is almost entirely composed of sandy beach deposits in the form of a barrier bar covered with high dunes fronting extensive marshes. Beach materials are glacial in origin. The visible sources of such materials on Plum Island are small. They consist of three drumlins and small patches of till and outwash at the southeast tip of the island. One drumlin is completely surrounded by dunes and marsh and has apparently never been eroded. One drumlin is one-half consumed by wave erosion and the other has been completely eroded and is now marked by a boulder pavement. Another visible onshore glacial deposit is the drumlin known as Great Boars Head, which projects seaward as a headland at Hampton Beach located about 7 miles north of the Merrimack River. Submerged offshore material is generally sandy, consisting of material laid down directly by glaciers or materials formerly transported downstream and deposited offshore by the Merrimack River.

11. Beach and Bottom Materials. - The shore of Plum Island and adjacent beaches to the north and south are almost exclusively composed of sand. The composition of Plum Island north of the Newbury-Rowley boundary consists of fine and medium sand in the dunes, medium sand with some fine and coarse sand in the vicinity of the high water level and medium to coarse sand between the mean high water and mean tide level. Samples taken in the river entrance and offshore from the north end of Plum Island indicate that offshore material is coarser than the beach material. Samples of offshore material from beaches north of Plum Island are finer than on the beaches. Median diameters of beach and offshore material sampled during prior investigations are included in Appendix B, and the sample locations are shown on Plate 1. These median diameters show that the coarsest material exists at the north end of Plum Island and that material becomes progressively finer to the north along Salisbury, Seabrook and Hampton Beaches and to the south

along Plum Island, Castle Neck and Coffin Beach. Median diameters and locations of samples taken on and offshore along the north end of Plum Island and in the Merrimack River entrance during June 1952 are shown on Plate 7.

12. Sources of Material. - Glacial deposits have constituted the principal source of beach materials. The sands comprising the barrier beach and dunes of Plum Island were derived from deposits of till and glacial outwash that constitute the hills and offshore deposits of the area. Material eroded from these deposits has been transported and redeposited by shore currents. Some of the material probably was derived from sediments transported by the Merrimack River and from beaches north of Plum Island. The visible sources of such materials are entirely inadequate to account for most of the materials composing Plum Island. The submerged offshore deposits appear to be the most important original source of supply for formation of the island. The present sources are shores to the north of the Merrimack River. The extensive outer bar is indicative of passage of material across the inlet.

13. Tides. - The tides at Plum Island are semidiurnal. The mean range of tide at the Merrimack River entrance is 8.0 feet and the spring range is 9.3 feet. The mean range of tide at Ipswich River near the south end of Plum Island is 8.7 feet and the spring range is 9.9 feet. Tides exceed the height of the plane of mean high water on an average approximately as follows; by 1 foot or more 107 times a year; by 2 feet or more 12 times a year; by 3 feet or more once every 2 years. The maximum storm tide height of 3.9 feet above mean high water was measured at the Portsmouth Navy Yard, Maine, on November 30, 1944. A description and analysis of available tidal observations for the area is contained in Appendix C.

14. Currents. - The mean currents for a section of the Merrimack River at the south jetty computed by cubature for a tidal range of 9.13 feet and a

fresh water flow of 4660 c.f.s. were as follows:

At strength of flood, 2.58 feet per second

At strength of ebb, 3.23 feet per second

River ebb currents measured by floats during November 1937 between the jetties at the Merrimack River entrance exceeded 6.0 feet per second. A maximum current of 6.5 feet was measured near the bend in the north jetty and a current of 6.2 feet was measured about 150 feet north of the south jetty. Current measurements were made using floats opposite Salisbury Beach north of the north jetty during 1931. Currents averaged 0.07 to 0.40 feet per second with maximum currents of 0.08 to 0.70 feet per second. Currents were tidal and moved alongshore south towards the mouth of the river on flood tide and away from the river in varying directions during ebb tide. No current measurements have been made opposite the shore of Plum Island. Details of available current data are included in Appendix D.

15. Prevailing Winds. - Wind data from observations of the United States Weather Bureau at Boston, Massachusetts, and from wind roses in the 5-degree square opposite the study area compiled by the United States Navy Hydrographic Office indicate that prevailing winds blow offshore from westerly quadrants. Winds from easterly quadrants which blow onshore over significant fetches of ocean are slightly predominant from the northeast over the southeast quadrant. A description and analysis of wind data are included in Appendix E, and wind roses are shown on Plate 1.

16. Storm Winds. - A summary of gales compiled from records of the United States Weather Bureau at Boston, Massachusetts, shows that of 160 gales which occurred during the 75-year period, 1870-1945, 80 or 50 percent were northeast gales. The high frequency of northeast winds of gale force (39 miles per hour or greater) is also evident from a study of hourly wind speeds and directions at Boston for the period April 1950 to March 1952. Analysis of all available data shows that a high preponderance of the most

severe gales which occur at Boston and, therefore, probably at Plum Island, approach onshore from the northeast direction and that winds of slightly smaller intensity predominantly blow offshore from the northwest quadrant. A description and analysis of storm wind data are included in Appendix E.

17. Waves. - Waves which approach the shore of Plum Island are generated by winds with easterly components of direction blowing across the Atlantic Ocean. The Isles of Shoals, 15 miles northeast of the Merrimack River entrance, afford a small amount of protection to Plum Island from waves generated by north to northeast winds, and Cape Ann affords protection, particularly to the south end of Plum Island, from waves generated by south to southeast winds. Plum Island is directly exposed to waves approaching from the east. No wave measurements are available for this area. The United States Navy Hydrographic Office has compiled observed data and prepared sea and swell charts for the North Atlantic Ocean. Sea directions in the ocean area opposite Plum Island are predominantly from the southwest, west and northwest or from directions which have little effect on Plum Island. Seas with easterly components approach predominantly from the northeast. High seas which cause the greatest erosion and shore damage occur predominantly from November through March. A swell diagram compiled from the above Hydrographic Office data is shown on Plate 1. It shows that high and medium swells having easterly components of direction approach predominantly from the northeast. In general, it can be concluded that high waves and swells attack Plum Island most frequently from the northeast. Available data does not permit determination of the maximum height of waves and swells.

18. Shore Line and Offshore Depth Changes. - Shore line and offshore depth change descriptions are based principally on surveys by the United States Coast and Geodetic Survey and the Corps of Engineers, United States Army. The former agency surveyed all of Plum Island and portions of adjoining beaches during 1851-1857 and portions of Plum Island and/or adjoining

beaches during 1878, 1910-1912 and 1928. The Corps of Engineers' surveys were made at comparatively frequent intervals during the period 1880-1938 covering the Merrimack River entrance and the northern portion of Plum Island extending not more than 4500 feet south of the south jetty. In addition, use was made of surveys of the Merrimack River entrance and the north end of Plum Island by Colonel John Anderson during 1827 and the Commonwealth of Massachusetts during 1952. Comparative shore line and offshore depth contour positions are shown on Plates 3-6. A detailed account of changes is included in Appendix F.

19. The largest known changes occurred to the north end of Plum Island during the period 1827-1880 before construction of the jetties at the Merrimack River entrance. According to the earliest available survey made during 1827, the Merrimack River entrance was located about one-half mile south of its present position and "The Basin" did not exist. During the period 1827-1851, the river entrance must have migrated further south, eroding the northeast end of Plum Island so that the seaward shore line was in the approximate position of the west shore of "The Basin." Still, during the same period following the southward river migration, a bar or spit formed at the north end of the island. The earliest U.S.C.&G.S. survey in 1851 shows this bar or spit extending in a northwestward direction from the northeast shore of Plum Island enclosing the body of water now known as "The Basin." The seaward shore of the bar or spit grew to the east and north during the period 1851-1880, resulting in northward growth of Plum Island and northward migration of the river channel. During the foregoing period, a recession occurred to the south shore of Salisbury Beach corresponding to the northward growth of Plum Island.

20. During the years immediately following initiation of construction of the north jetty in 1881 and the south jetty in 1883, large amounts of accretion occurred to the seaward shores of Plum Island and Salisbury

Beach adjacent to the jetties. This growth has not been a continuous process. Numerous surveys run during and after construction of the jetties show that both shores have been subject alternately to erosion and accretion. Accretion has been slightly predominant north of the north jetty along Salisbury Beach. Shore line changes south of the south jetty along Plum Island have been so varied and complicated that it is not possible to determine whether erosion or accretion is predominant. The north end of the island inside the jetties although subject to irregular shore line changes during the years following the jetty construction has shown a definite tendency towards northward growth. This growth has been accompanied by a northward migration of the river channel and a northward recession of the river shore of Salisbury Beach.

21. The most recent shore line changes at the north end of Plum Island as shown by the U.S.C.&G.S. survey of 1928 and the Commonwealth of Massachusetts survey of 1952 consisted principally of a northward growth of the north shore of Plum Island inside the jetties of 600 to 700 feet, a recession of the seaward shore adjacent to the south jetty of about 100 feet diminishing to a point of no change about 2,000 feet south of the jetty, little change along the next southerly 1,400 feet and a continuous shore recession along the shore located 3,400 to 11,000 feet south of the jetty. This latter recession was approximately as follows; 150 feet opposite the south end of "The Basin," 250 feet midway between "The Basin" and the seaward end of Plum Island Turnpike, 100 feet at Plum Island Turnpike, 150 feet fronting the cottages south of the turnpike and 200 feet along 2,000 feet of shore south of the cottages.

22. Shore line changes along the seaward shore of Plum Island south of "The Basin" have not been as large as those further north. Between 1852 and 1928 the shore located 700 to 5,400 feet south of "The Basin" was subject to both erosion and accretion, with accretion predominant,

resulting in a seaward movement of this entire shore. The maximum seaward movement of about 200 feet occurred at the south end of this area. During the same period, the shore located 5,400 to 11,100 feet south of "The Basin" also grew or moved seaward for distances varying between 50 and 200 feet. Only one survey of the central portion of Plum Island is available so it is not possible to make a comparison of changes for this area. Between 1853 and 1912, the seaward shore of Plum Island located 8,800 to 14,800 feet north of the southeast end of the island grew about 50 feet seaward while 5,400 feet of shore south of this area receded about 50 feet and no measurable change occurred in the vicinity of the southeast end of the island. Between 1853 and 1912, the southwest end of Plum Island grew 1,200 to 1,500 feet southward. Large changes occurred along the Castle Neck shore between 1853-1855 and 1910-1911. These changes consisted of accretion or seaward movement of the shore line up to maximum distance exceeding 900 feet.

23. The principal changes in offshore depths were as follows; (1) with northward growth of Plum Island and northward recession of the south end of Salisbury Beach, a submarine bar grew from the north end of Plum Island into the Merrimack River inside the jetties towards the bend of the north jetty deflecting the continuous river channel closer to Salisbury Beach and scouring a deep hole parallel and very close to the shore arm of the north jetty; (2) construction of the jetties was followed by deepening of the continuous river channel across the outer bar opposite the river entrance and elimination of the large migrations of the river entrance which formerly occurred. Changes in the direction of flow of the channel across the outer bar outside the jetties continued, the predominant tendency of the channel being to flow in a direction slightly south of east; (3) the large outer bar at the river entrance migrated following migrations of the river entrance, becoming wider in the vicinity of the deep continuous river channel and eroding at

former locations of the river channel; (4) depths on the large outer bar at the river mouth have varied irregularly through the formation of smaller bars or shoals, particularly opposite the north end of Plum Island south of the south jetty. In recent years, as shown by surveys during 1928 and 1952, the smaller bars opposite the north end of Plum Island have had a general northeast-southwest orientation parallel to the depth contours defining the seaward edge of the larger outer bar, they have grown in size and moved southward away from the south jetty and they have been separated from the foreshore slope of Plum Island by a deepening channel or trough; (5) available surveys made during 1851-1857 and 1928 indicate that offshore deepening and landward movement of offshore depth contours was occurring opposite 11,000 feet of shore south of "The Basin." Due to lack of comparative surveys, it is not possible to determine offshore depth changes opposite the remainder of Plum Island.

24. Shore Structures. - There are no significant structures within the study area built solely for the purpose of shore protection. Two existing jetties at the mouth of the Merrimack River were constructed by the United States as a Federal project for improvement of the river entrance for navigation purposes. The north jetty was started in 1881 and completed to a length of 4,118 feet in 1914. The south jetty was started in 1883 and completed to a length of 2,415 feet in 1905. Both jetties were constructed of rubblestone with a top width of 15 feet at an elevation 12 feet above mean low water and side slopes of 1 on 2 on the seaward side and 1 on 1 on the river side. The inshore arms of the jetties converge seaward until they are about 1,000 feet apart and the outer arms extend seaward parallel to each other for a distance of about 1,000 feet. Prior to construction of the jetties, the mouth of the Merrimack River was subject to large migrations. A southward migration of the river mouth formerly resulted in erosion and loss of the entire northeast corner of Plum Island located east and north of

"The Basin." The jetties have successfully fixed the position of the river mouth thereby making utilization of the land area east and north of "The Basin" possible. This area is now largely occupied by cottages. The jetties resulted in impounding of material and accretion of the seaward shore of Salisbury Beach and Plum Island adjacent to the jetties during the early years after their construction was started. Since that time, these shores have been subject alternately to accretion and erosion. Accretion has been slightly predominant over erosion north of the north jetty at Salisbury Beach thus benefitting this beach. Shore line changes south of the south jetty along Plum Island have been complex with no apparent predominance of either erosion or accretion. These complex changes have been large and rapid and are apparently influenced more by the shifting of the outer bar opposite the river entrance than by the south jetty. A detailed history of construction of the jetties and changes in the vicinity of the river mouth associated with their construction is included in Appendix G. This Appendix also contains an account of structures which formerly existed, namely, a dike across the entrance of "The Basin" constructed during 1883-1884 to prevent breaching of Plum Island and formation of a new river entrance opposite the south end of "The Basin," and sand catches, constructed during fiscal years 1884-1887 to build up the beach and prevent flanking of the shore end of the south jetty.

25. Littoral Drift. - The predominant direction of littoral drift along the shore of the region from Boars Head to Castle Neck is from north to south. Evidence of southward drifting consists of accretion along Salisbury Beach, north of the north jetty at the Merrimack River entrance, presumably resulting from impounding of beach material by the jetty. In the early years after initiation of construction of the north jetty, this accretion was rapid. After this early period during which the beach was assuming a new condition of equilibrium, Salisbury Beach has been subject

alternately to accretion and erosion with accretion slightly predominant. It was reported in the beach erosion control report on Salisbury Beach in 1941 that the efficiency of the north jetty was improved by repairs made during 1937 as evidenced by advancement of the high and low water shore lines during the ensuing three-year period, 1937-1940. Under conditions of strong littoral drift along the many miles of sandy shore north of the north jetty, a continuous impounding of material by the jetty and a consequent continuous accretion of the shore would be a natural expectation. The absence of continuous accretion indicates that no such strong predominantly southward drift occurs, that variations in direction of drift tend to balance each other, or that on and offshore movement of material plays a large part in building up or eroding of the shore line. Other evidence of southward littoral drifting consists of the large amount of accretion known to have occurred in the Castle Neck region south of Plum Island, the material for this accretion being derived from the loss and southward movement of material from the beaches to the north.

26. Littoral drift in the vicinity of the Merrimack River entrance along the shore of Plum Island north of "The Basin" is influenced by strong tidal currents and by the formation of a bar opposite the mouth of the river. Northward growth of Plum Island in the past by the formation of bars or spits trailing westward into the river mouth indicate that the direction of drift along the north shore of the island is westward or upstream, probably a result of flood currents. The seaward edge of the bar at the mouth of the Merrimack River is convex shaped. Such a bar would ordinarily tend to refract waves approaching the shore bending them towards the river mouth causing material to drift northward along the north end of Plum Island. The large northward growth known to have occurred to Plum Island prior to construction of the jetties may largely have been due to the configuration of the outer bar, possibly during a period when storms approached the shore

predominantly from a southeast direction. The depths on the outer bar and the configuration of shoals on it have varied greatly during the past, the changes resulting partly from variations in the direction of flow of the continuous river channel across the bar. These changes are believed to have resulted in complex localized movements of material along the seaward shore of the north end of Plum Island. The configuration of shoals on the outer bar as shown by a hydrographic survey during 1952 indicates that waves would tend to be refracted so as to move material northward and southward away from a point opposite the narrowest part of Plum Island in the vicinity of the south end of "The Basin." Such drifting could account in part for the serious condition of erosion which has developed in recent years at this part of the island.

27. Available surveys do not permit calculation of the rate of impoundment of material by the Merrimack River jetties. It was reported in the beach erosion control report on Salisbury Beach (1941) that a net accretion of 1,600,000 cubic yards occurred between the high water line and the 18-foot depth for the full length of Salisbury Beach during the period 1931-1940, a rate of about 180,000 cubic yards annually. Since the shore involved extends approximately three and one-half miles northward from the north jetty, the rate of accretion does not represent the rate of impoundment by the jetty.

IV. ANALYSIS OF PRINCIPAL FEATURES OF THE PROBLEM

28. General. - In recent years, the shore line along the northern end of Plum Island has been subject to intermittent erosion and accretion, with shifting of the eroding area alongshore and a resulting gradual recession of the shore as a whole. The beach in this area is narrow and steep and storm waves accompanying high storm tides can pass over the beach berm and erode the dunes. Large volumes of material are removed in localized areas during severe storms but the areas of erosion shift and former eroding areas are at least partially restored.

29. Rates of Supply and Loss. - No information is available concerning the rates of supply and loss for Plum Island as a whole. Available surveys run during the period from 1851 to 1880 before construction of the jetties at the Merrimack River entrance, show that the mouth of the river was migrating northward. Following the jetty construction, the north end of Plum Island or its shore line along the Merrimack River continued to advance northward. An estimate of the quantity of material added to the northern end of Plum Island between 1940 and some time between 1827 and 1851 (from figures contained in "The Geology of the Coast of Northeastern Massachusetts" by N. E. Chute and R. L. Nichols) indicates an average rate of accretion of nearly 100,000 cubic yards per year. The recession of the seaward shore of Plum Island occurring during recent years along the northern section of the island indicates that in localized areas south of the jetty, for short periods at least, the rate of loss exceeds the rate of supply.

30. Manner of Movement of Materials. - Since 1827, large changes have taken place in the configuration of the shore line at the northern end of Plum Island. This end of the island is forked and there is now a shallow body of water known as "The Basin" between the two prongs of the fork. Interpretation of early surveys indicates that the Merrimack River entrance was formerly migrating southward in the accepted direction of the predominant littoral drift. At some time during the period 1827-1851, possibly under the influence of southeast storms or as a result of passage of material across the river mouth, a bar or spit formed at the northeast end of Plum Island, enclosing "The Basin." The Merrimack River entrance progressively moved northward in conjunction with growth of this bar or spit. Since construction of the south jetty, during the period 1883-1905, the northern tip of Plum Island has continued to grow into the river channel and, as a result of accretion, about 700 feet of the shoreward end of the south jetty, which

had been constructed seaward of the shore line, is now covered with sand. Sand has passed over or through the jetty during and since its construction. During the immediate years after repairs to the jetties in 1937, it was reported that more material was impounded by the north jetty than in the years immediately preceding the repairs.

31. The immediate effects of the jetty construction were that the ocean shore of Plum Island south of the south jetty and the Salisbury Beach shore north of the north jetty advanced rapidly. Littoral drift moves around the outer ends of the jetties over the prominent outer bar which extends about a mile south of the entrance. Some of this material, enroute to the south side of the river, is also moved into and out of the channel and deposited offshore by tidal currents.

32. During severe storms, large, rapid movements occur in localized areas along the northern ocean shore of Plum Island resulting in large losses of beach material. Some of this movement is landward as a result of winds blowing sand from the beach and dunes. The greater part of these losses are effected by wave action which attacks and erodes the beach and dunes and carries the material seaward. Some of the material is probably carried north or south by littoral currents depending upon the direction of waves when they strike the shore. The outer bar which extends south from the river entrance reduces wave heights on the shore for about a mile south of the south jetty. Variations in depths occur on the outer bar, however, which result in variations in heights of waves reaching this shore. It appears that the changes in depth on the outer bar and the orientation of smaller bars or shoals which form on the outer bar may be responsible for variations in the point of severest attack and shifting of the eroding area alongshore. The one-quarter mile reach of shore immediately south of the south jetty is sheltered from wave action to some degree by the jetty and offshore bar fronting that reach. The next southerly one-mile stretch

of shore which includes the narrowest portion of the island opposite "The Basin" is more exposed to storm waves which severely attack and erode the beach and dunes. Consequently, it is along this reach that the most unfavorable balance between rates of supply and loss exists.

33. Method of Modifying Rates of Supply and Loss. - The major force causing the loss of beach material in the problem area is storm wave action. The greatest portion of the normal supply of littoral drift probably moves along the offshore bar under the influence of normal wave action and does not reach the beach along the northern 1-1/4 miles of the Plum Island shore line. Groins would have to extend beyond the offshore bar and average more than 1,000 feet in length in order to be effective in trapping normal littoral drift. Shorter groins in this area would probably be effective to a limited extent only in retarding sand losses from the beach during storms. In view of the complex situation resulting from the instability of the offshore bar, it is improbable that groins would be sufficiently effective to be economically justified. The rate of loss can also be reduced by construction of an offshore breakwater to decrease the amount of wave energy reaching the shore. This method has the disadvantages of high initial cost and possible adverse effect on adjacent shores. The remaining alternative is to increase the rate of supply by artificially adding sand to the beach in the problem area. This method appears to be the most practicable and economical. The large volume of sand that has accumulated in the Merrimack River at the northern tip of Plum Island inside the south jetty, offers a suitable and convenient source from which sand could be supplied to the beach in the problem area by hydraulic dredging.

34. Design Criteria. - A plan of protection for the urgent problem area at the north end of Plum Island should provide that the existing eroded bight or indentation in the shore line be filled to the general alignment of the adjacent high water shore line with sand of size equal to or greater

than that now composing the beach. Observations at the Portsmouth Navy Yard, about 17.4 miles north of the Merrimack River entrance, over an 18-year period, indicate that tides exceeding a height of three feet above the plane of mean high water, corresponding to a tide of 11 feet above the plane of mean low water at the north end of Plum Island, occur on an average once in two years. At a high tide stage of 11 feet, the maximum height of waves reaching the low water line without breaking would be about nine feet and two feet at the high water shore line. An elevation of berm for the fill of 12 feet (m.l.w.) would be the minimum necessary under these conditions. The quantity of fill placed should be determined by the average profile conditions of existing adjacent beaches. For the minimum quantity necessary, the volume of fill should be computed assuming a slope of 1 on 12.5 from the mean low water line up to the top of the berm, and 1 on 20 below the mean low water line. The mean low water line of the fill should be about 100 feet seaward of the mean high water line.

35. Fill placed in accordance with these criteria would provide a minimum width of beach of 100 feet at elevation 12 feet (m.l.w.) or higher in front of all buildings along the problem area. Even if recession of the shore line continued at the maximum reported past rates, such a beach would provide adequate protection for at least two years. It is considered unlikely that erosion will continue at so great a rate in the same localized area, but in any event periodic placement of additional fill will be required in the shifting zones of severe localized erosion.

V. PLAN OF PROTECTION

36. Plan Selected. - Of the possible remedial measures, namely: (a) structures to reduce the rates of loss of material such as groins, revetment or a seawall; (b) structures to prevent storm waves from attacking the beach such as an offshore breakwater, and (c) artificially increasing the sand supply to the problem area by direct placement of sand fill - plan

(c) is selected as the most practicable solution. The section of shore on which fill should be placed extends from a point about 3,000 feet south of the south jetty to a point near the seaward end of Plum Island Turnpike, a distance of approximately 3,000 feet. The high and low water shore lines along this section are indented landward as much as 125 feet and 150 feet, respectively, from the general shore alignment. The center of this section is also the location of the narrowest strip of land between "The Basin" and the Atlantic Ocean. The plan selected would advance the high water shore line in this indented section of shore into a general alignment with the high water shore line north and south thereof. The sand fill should be in such quantity as to provide a flat berm at about elevation 12 feet above mean low water extending seaward about 100 to 150 feet in front of existing cottages and thence sloping at about 1 on 12.5 down to mean low water. The quantity of sand fill placed should be sufficient to advance the low water shore line about 100 feet seaward of the high water shore line. If it is assumed that the fill material will adjust itself to an average slope of 1 on 20 seaward of the low water shore line, the estimated quantity of required fill will be 285,000 cubic yards. This fill should add sufficiently to the general width of the shore in front of the cottage development so that during subsequent shifts of the eroding area during the next few years, the width of protective beach will not be diminished sufficiently to endanger the cottage development. Losses of material will necessitate replenishment of the sand fill to insure maintenance of an adequate width of protective beach. The placement of approximately 180,000 cubic yards of sand on eroding areas at intervals of five years is considered sufficient to maintain a suitable protective beach. In view of losses of beach material northward over the inshore end of the south jetty into the Merrimack River, it would be advisable to raise the inshore portion of the jetty to an elevation of about 16 feet above mean low water as may be required to act as a barrier to northward drift.

37. Estimated Cost. - Amortization charges are based on a life of the project of 50 years. The rate of interest on the investment is computed at 3.5 percent. The maintenance requirement for the sand fill is based on the average rate of loss of beach material in the area between the seaward end of Plum Island Turnpike and the south jetty as determined from comparative surveys run during 1928 and 1952. All costs are non-Federal costs.

a. First Costs

Sand fill, 285,000 cubic yards @ $1.00	$285,000
Raising jetty, 2500 tons riprap @ $10.00	25,000
Engineering and contingencies	75,000
Total First Cost	$385,000

b. Annual Charges

Interest	$ 13,475
Amortization	2,925
Maintenance 36,000 cubic yards sand fill @ $1.00	36,000
Total Annual Charges	$ 52,400

38. Comments of The Cooperating Agency. - Close contact has been maintained during the study with the cooperating agency, the Massachusetts Department of Public Works. Several conferences were held and a copy of the draft of the report was reviewed by this agency. The cooperating agency believes that the proposed plan of protection will fulfill the purpose of the State legislation which authorized the study, and it is in full accord with the recommendations contained in the report.

VI. CONCLUSIONS AND RECOMMENDATIONS

39. Conclusions. - The Division Engineer concludes that the plan of protection described in Part V of this report and shown on Plate 7 of the drawings is the most suitable method of stabilizing the shore and protecting shore front cottages and Northern Boulevard.

40. Shore front property to be protected is almost entirely privately-owned. The extent of publicly-owned shore front property is minor, consisting of one street end and some narrow rights-of-way extending to the shore between cottages. Since Federal participation in the cost of protecting privately-owned shores would not be in accordance with existing laws, it is concluded that Federal assistance for such work cannot be recommended at this time.

41. Recommendations. - It is recommended that no project be adopted by the United States for protection of the shore of Plum Island within the City of Newburyport and the Town of Newbury. It is further recommended that protective measures which may be undertaken by local interests, based upon their determination of economic justification, be accomplished in accordance with plans and methods proposed in this report. The plan proposed for protection of the present problem area consists of, (1) direct placement of sand fill to widen the beach fronting cottages and dunes along that portion of the seaward shore of Plum Island located between points approximately 3,000 and 6,000 feet south of the south jetty at the Merrimack River entrance, and (2) raising the elevation of the inshore portion of the south jetty, as may be required, to act as a barrier to northward drifting and loss of beach material into the Merrimack River.

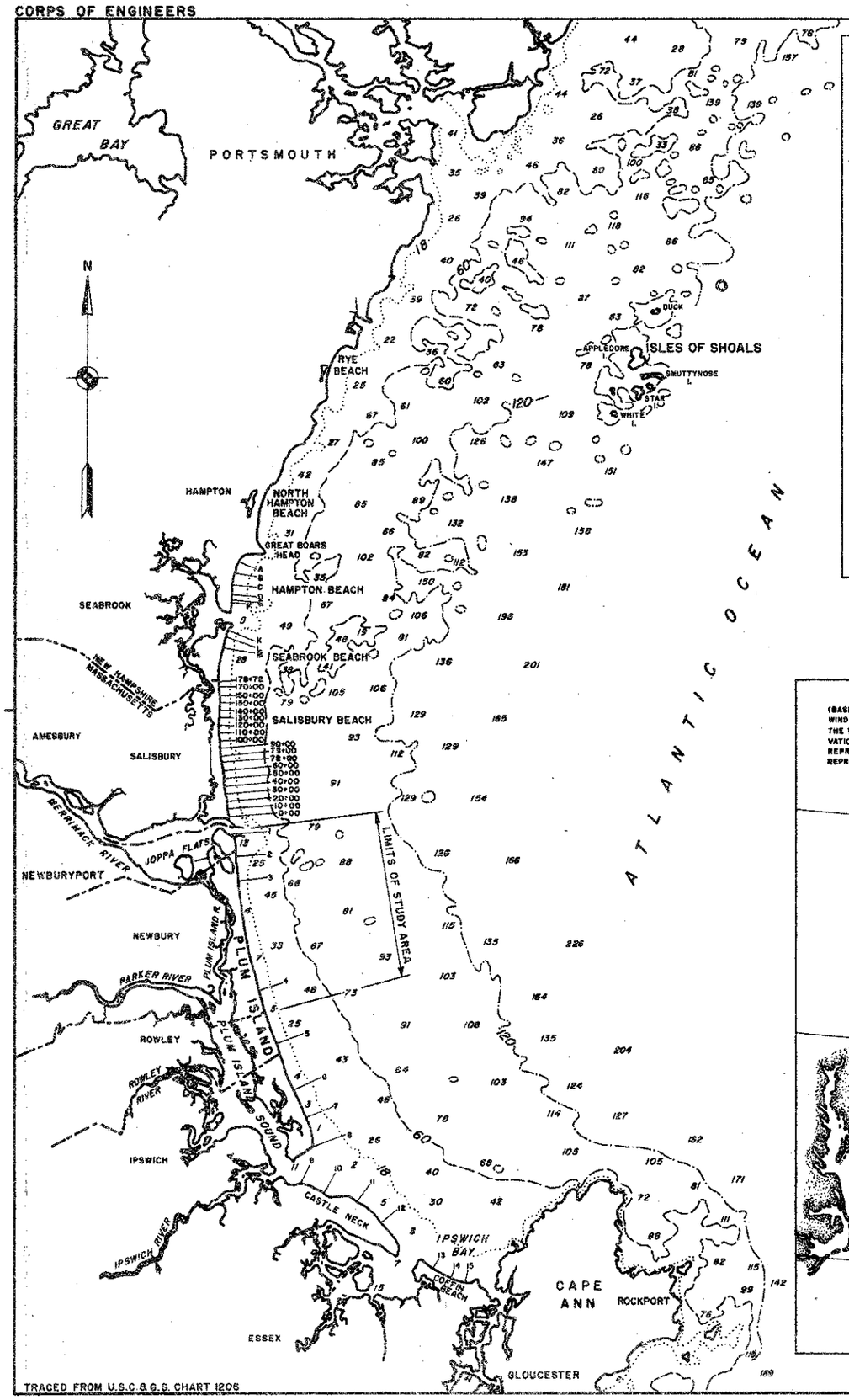
42. It is further recommended that protective measures along other portions of the seaward shore of Plum Island, that may be required as a result of shifting of the area of erosion, be accomplished by local interests, based upon their determination of economic justification, in the same manner as described for the present problem area.

15 Inclosures:
8 Appendices
7 Plates

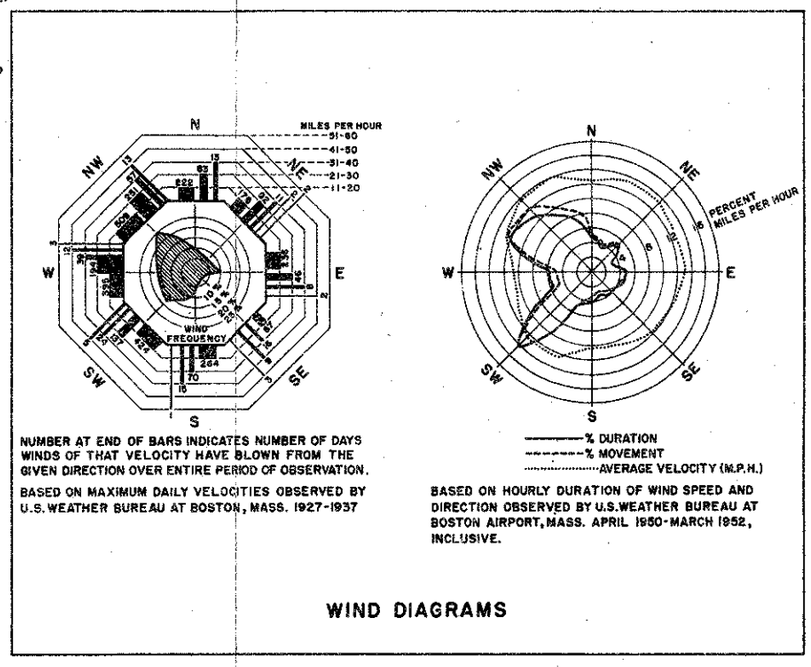
L. H. HEWITT
Colonel, Corps of Engineers
Division Engineer

CORPS OF ENGINEERS

U. S. ARMY



TRACED FROM U.S.C.&G.S. CHART 1205

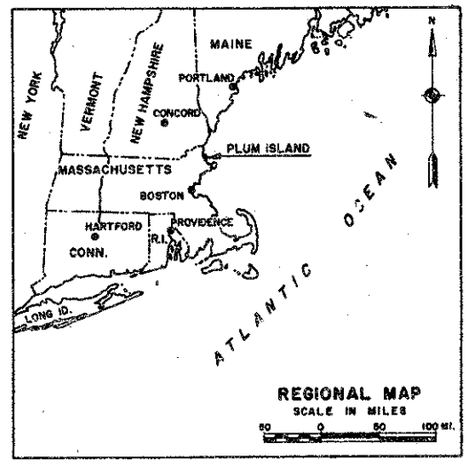


NUMBER AT END OF BARS INDICATES NUMBER OF DAYS WINDS OF THAT VELOCITY HAVE BLOWN FROM THE GIVEN DIRECTION OVER ENTIRE PERIOD OF OBSERVATION.

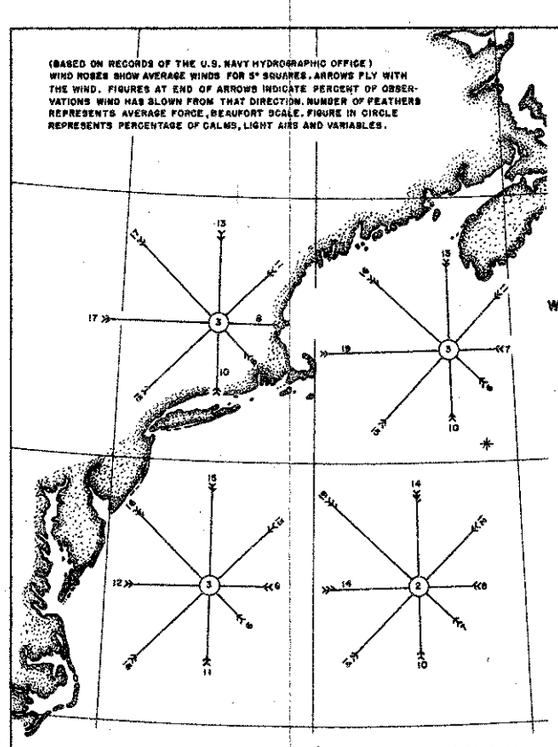
BASED ON MAXIMUM DAILY VELOCITIES OBSERVED BY U.S. WEATHER BUREAU AT BOSTON, MASS. 1927-1937

BASED ON HOURLY DURATION OF WIND SPEED AND DIRECTION OBSERVED BY U.S. WEATHER BUREAU AT BOSTON AIRPORT, MASS. APRIL 1950-MARCH 1952, INCLUSIVE.

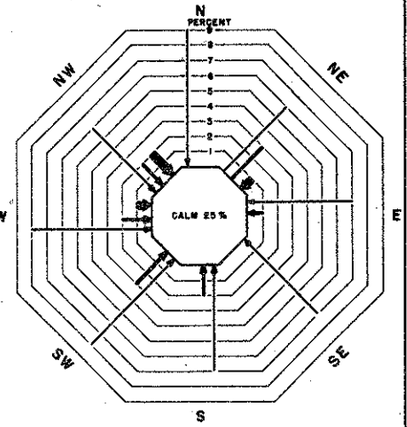
WIND DIAGRAMS



(BASED ON RECORDS OF THE U.S. NAVY HYDROGRAPHIC OFFICE)
WIND ROSES SHOW AVERAGE WINDS FOR 5° SQUARES. ARROWS FLY WITH THE WIND. FIGURES AT END OF ARROWS INDICATE PERCENT OF OBSERVATIONS WIND HAS BLOWN FROM THAT DIRECTION. NUMBER OF FEATHERS REPRESENTS AVERAGE FORCE, BEAUFORT SCALE. FIGURE IN CIRCLE REPRESENTS PERCENTAGE OF CALMS, LIGHT AIRS AND VARIABLES.



✳SWELL DIAGRAM FROM OBSERVATIONS IN THIS 5° SQUARE



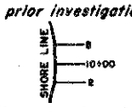
——— LOW SWELLS-----(1-6 FT.)
——— MEDIUM SWELLS-(6-12 FT.)
▬▬▬ HIGH SWELLS-----(OVER 12 FT.)

ARROWS INDICATE THE COURSE OF SWELLS. LENGTH OF BAR DENOTES PERCENT OF TIME THAT SWELLS MOVED FROM OR NEAR GIVEN DIRECTION. FIGURE IN CENTER OF DIAGRAM INDICATES CALMS. SWELL DATA BASED ON OBSERVATIONS FOR 10 YEAR PERIOD, 1932-1942 IN 5° SQUARE INDICATED ON MAP SHOWING PREVAILING WINDS.

PREVAILING WINDS AND SWELLS

NOTES

Locations of beach and offshore samples taken during prior investigations shown thus:



For samples taken for this study during 1952 see Plate 7.

BEACH EROSION CONTROL STUDY OF PLUM ISLAND, MASSACHUSETTS

GENERAL MAP

IN 1 SHEET — SCALE IN FEET 5000 0 10000 20000

NEW ENGLAND DIVISION, BOSTON, MASS. JUNE 27, 1952

APPROVED: John C. Allen, CHIEF, ENGINEERING DIVISION

APPROVED: [illegible], COL. C.E., DIVISION ENGINEER

SUBMITTED: [illegible], CHIEF, PLANNING AND REPORTS BRANCH

TRANSMITTED WITH REPORT DATED: AUG. 29, 1952

Francis W. Fitzgerald, CHIEF, RIVER AND HARBOR SECT.

DR. BY: A.L.D. TR. BY: A.L.D. CH. BY: [illegible]

FILE NO. B.E.Pm.Id.1

PLATE 1

CORPS OF ENGINEERS

U. S. ARMY

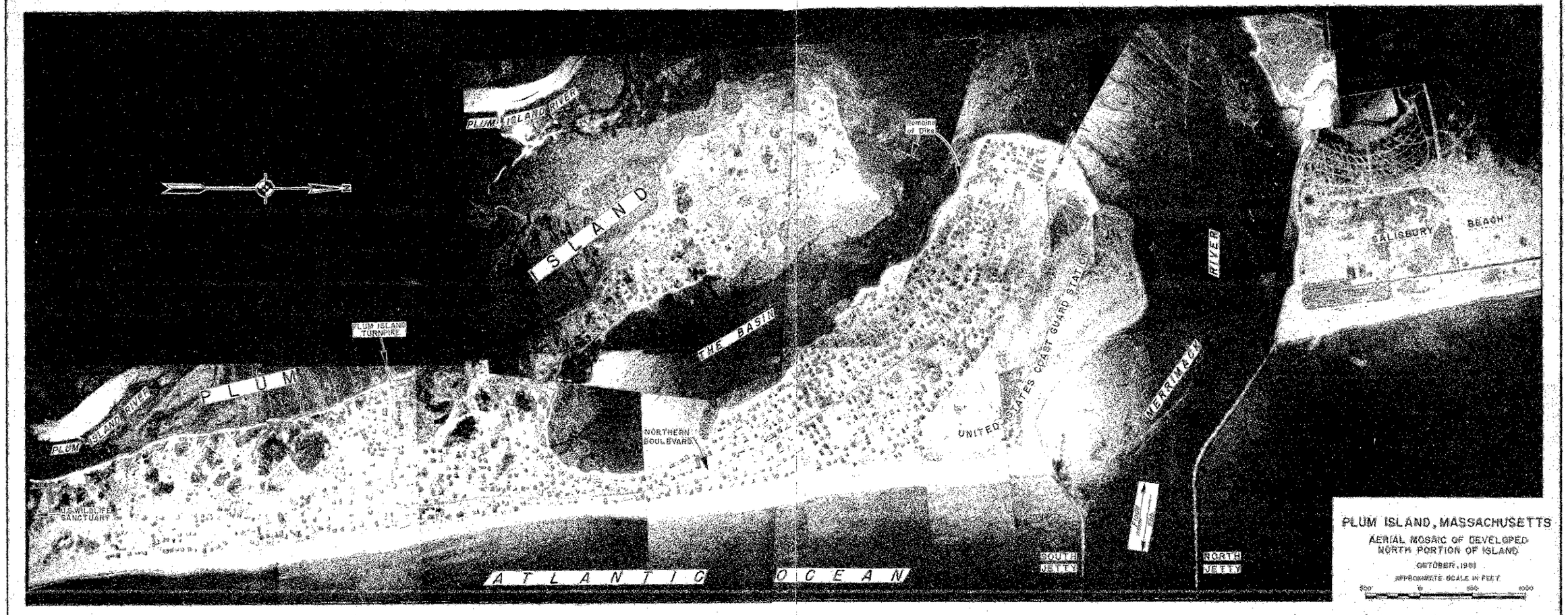


PLATE 2

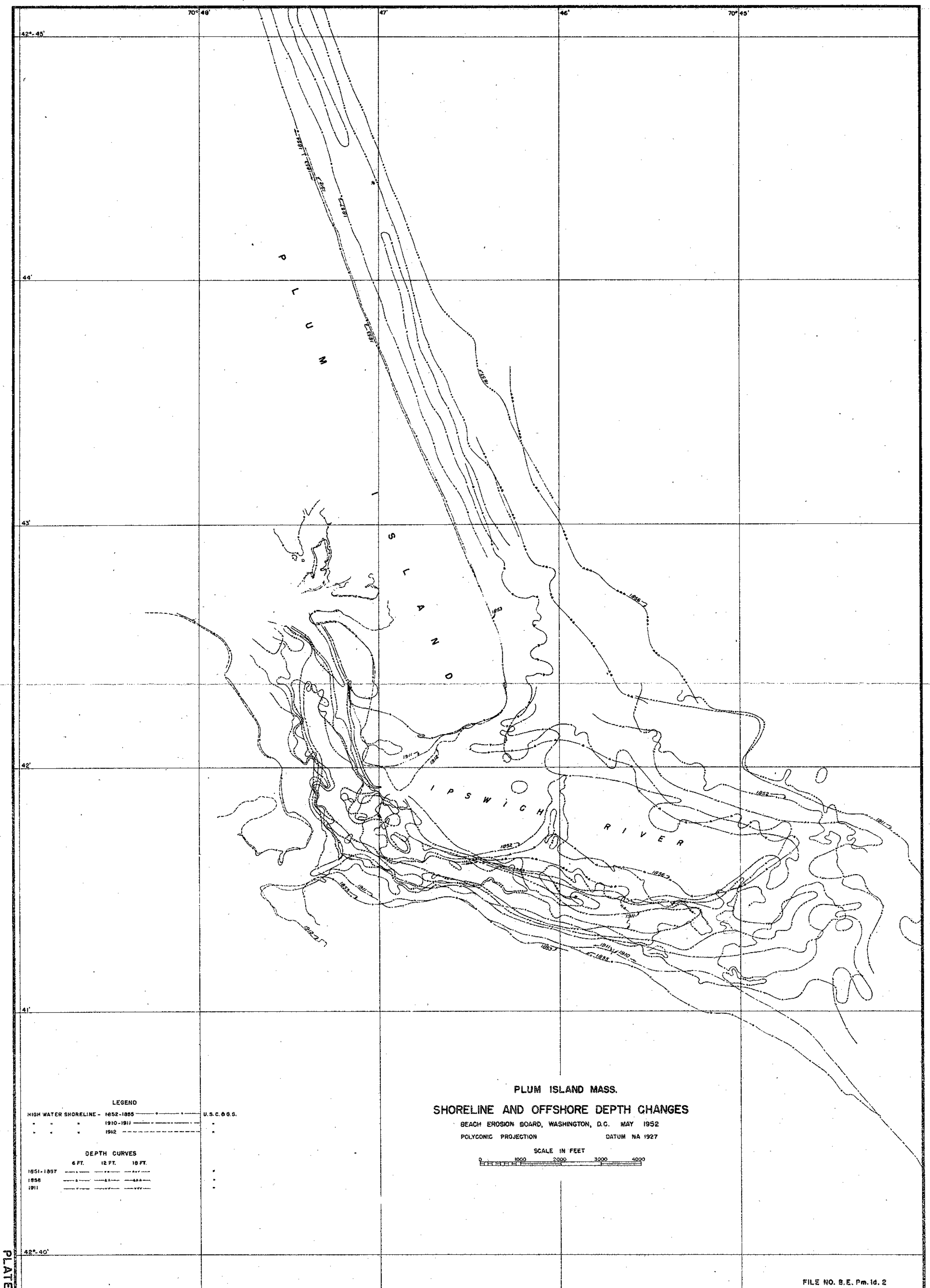
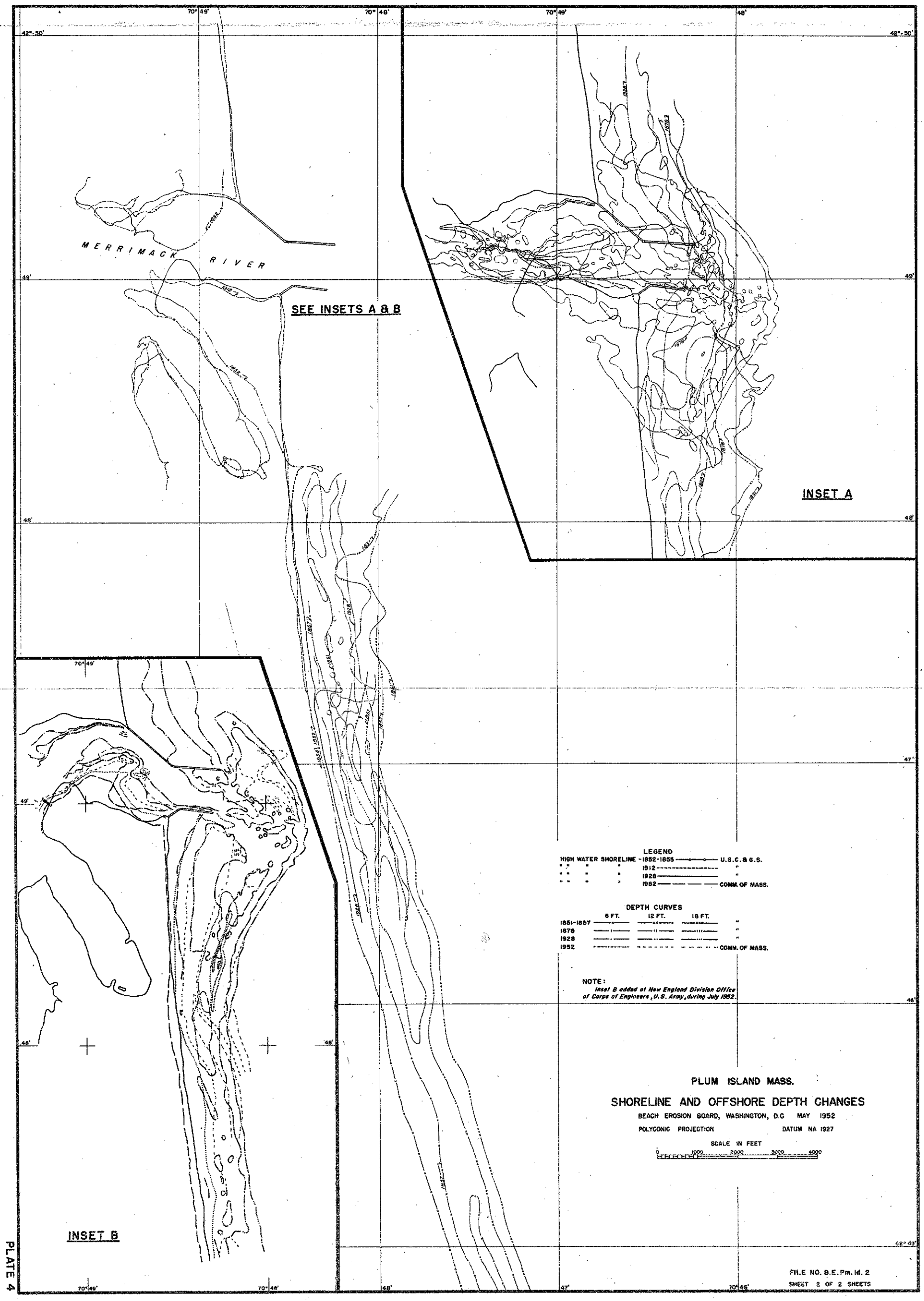
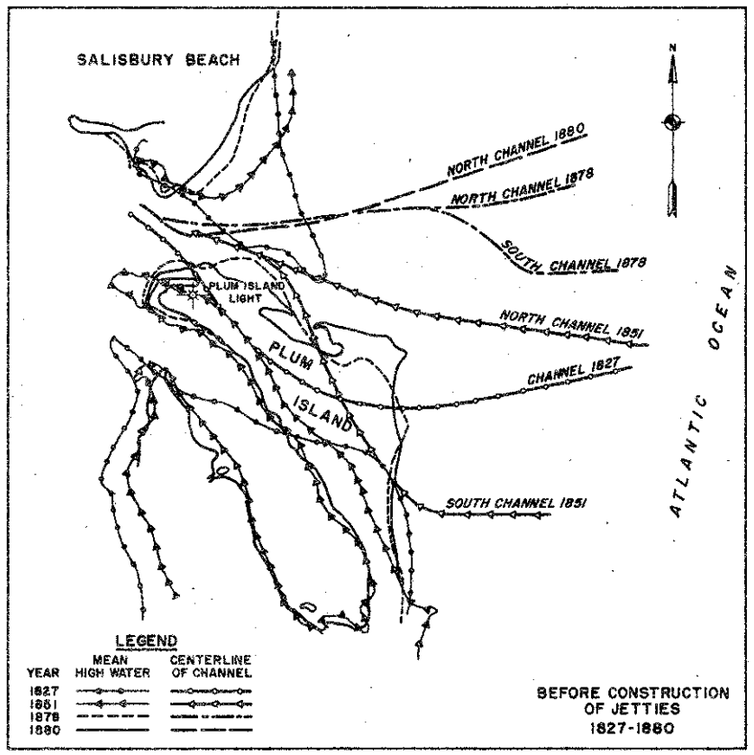
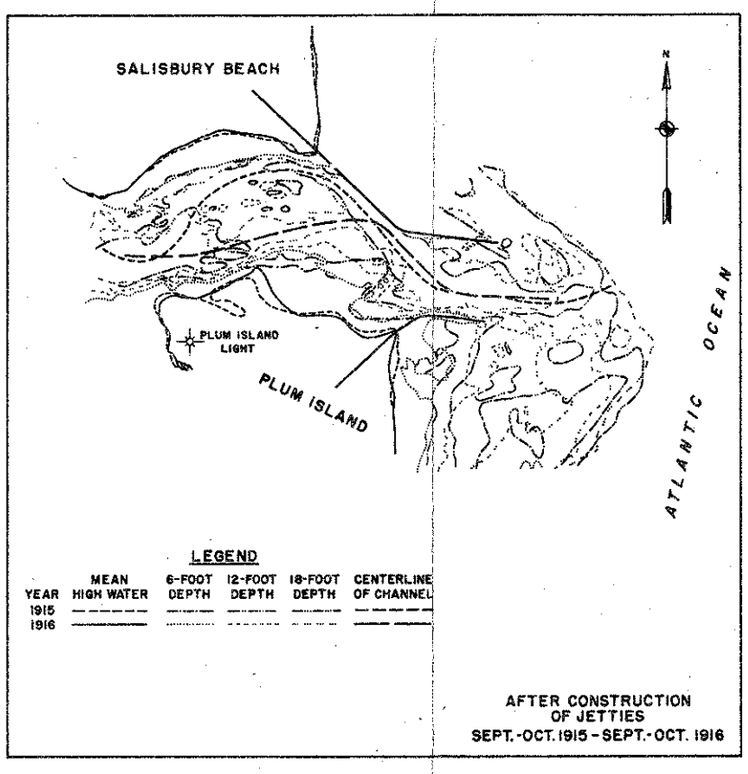

PLUM ISLAND
IPSWICH RIVER
PLUM ISLAND MASS.
SHORELINE AND OFFSHORE DEPTH CHANGES
BEACH EROSION BOARD, WASHINGTON, D.C. MAY 1952
POLYCONIC PROJECTION
DATUM NA 1927
SCALE IN FEET
0 1000 2000 3000 4000
LEGEND
HIGH WATER SHORELINE - 1852-1855 U.S.C.&G.S.
1910-1911
1912
DEPTH CURVES
6 FT. 12 FT. 18 FT.
1851-1857
1856
1911
FILE NO. B.E. Pm. Id. 2
SHEET 1 OF 2 SHEETS

PLATE 3

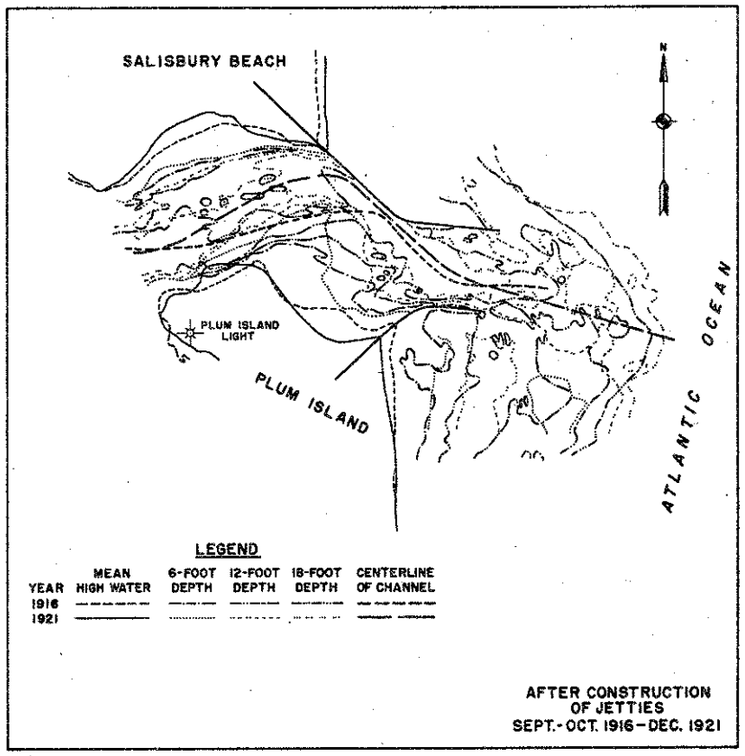

70° 49'
70° 48'
42° 50'
49'
48'
47'
46'
MERRIMACK RIVER
SEE INSETS A & B
INSET A
INSET B
LEGEND
HIGH WATER SHORELINE - 1852-1855 — U.S.C.& G.S.
1912 — "
1926 — "
1952 — COMM. OF MASS.
DEPTH CURVES
6 FT. 12 FT. 18 FT.
1851-1857 — "
1878 — "
1928 — "
1952 — COMM. OF MASS.
NOTE:
Inset B added at New England Division Office of Corps of Engineers, U.S. Army, during July 1952.
PLUM ISLAND MASS.
SHORELINE AND OFFSHORE DEPTH CHANGES
BEACH EROSION BOARD, WASHINGTON, D.C MAY 1952
POLYCONIC PROJECTION DATUM NA 1927
SCALE IN FEET
0 1000 2000 3000 4000
PLATE 4
FILE NO. B.E.Pm.Id. 2
SHEET 2 OF 2 SHEETS



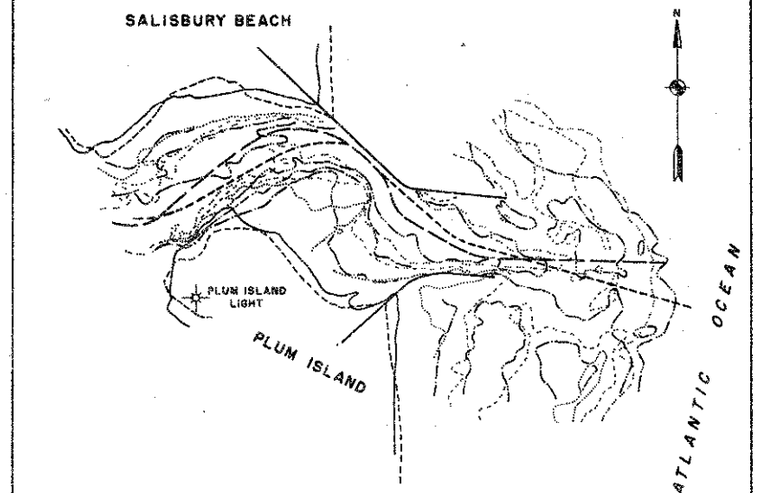
BEFORE CONSTRUCTION OF JETTIES 1827-1880



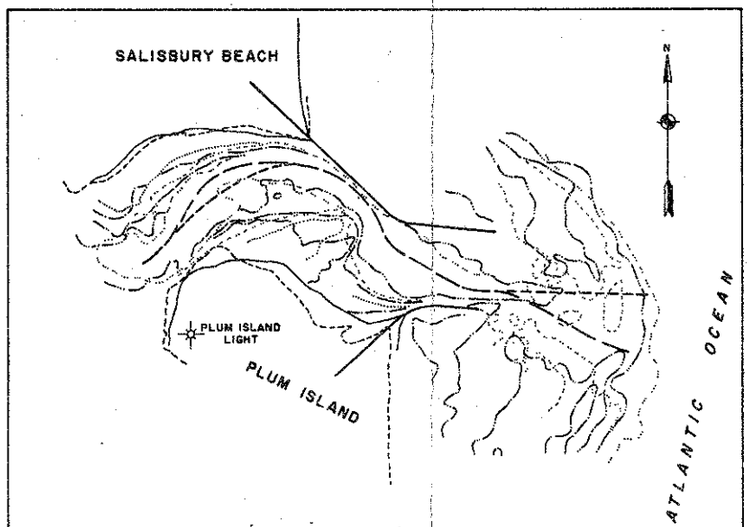
AFTER CONSTRUCTION OF JETTIES SEPT.-OCT. 1915 - SEPT.-OCT. 1916



AFTER CONSTRUCTION OF JETTIES SEPT.-OCT. 1916 - DEC. 1921



AFTER CONSTRUCTION OF JETTIES DEC. 1921 - JUNE-JULY 1931



AFTER CONSTRUCTION OF JETTIES JUNE-JULY 1931 - JULY-NOV. 1938

NOTES

Depths are referred to the plane of Mean Low Water.

Shore lines and offshore depths are from the following surveys:

Year	Source
1827	Col. John Anderson
1851 & 1878	U.S. Coast and Geodetic Survey
1880, 1915 & 1916	Corps of Engineers, U.S. Army
1921, 1931 & 1938	Corps of Engineers, U.S. Army

BEACH EROSION CONTROL STUDY OF PLUM ISLAND, MASSACHUSETTS

SHORE LINE & OFFSHORE DEPTH CHANGES BEFORE & AFTER CONSTRUCTION OF JETTIES

IN 1 SHEET — SCALE IN FEET 1000 0 1000 2000

NEW ENGLAND DIVISION, BOSTON, MASS. JULY 3, 1952

APPROVED: John E. Allen, CHIEF, ENGINEERING DIVISION

APPROVED: COL. C.E., DIVISION ENGINEER

SUBMITTED: CHIEF, PLANNING AND REPORTS BRANCH

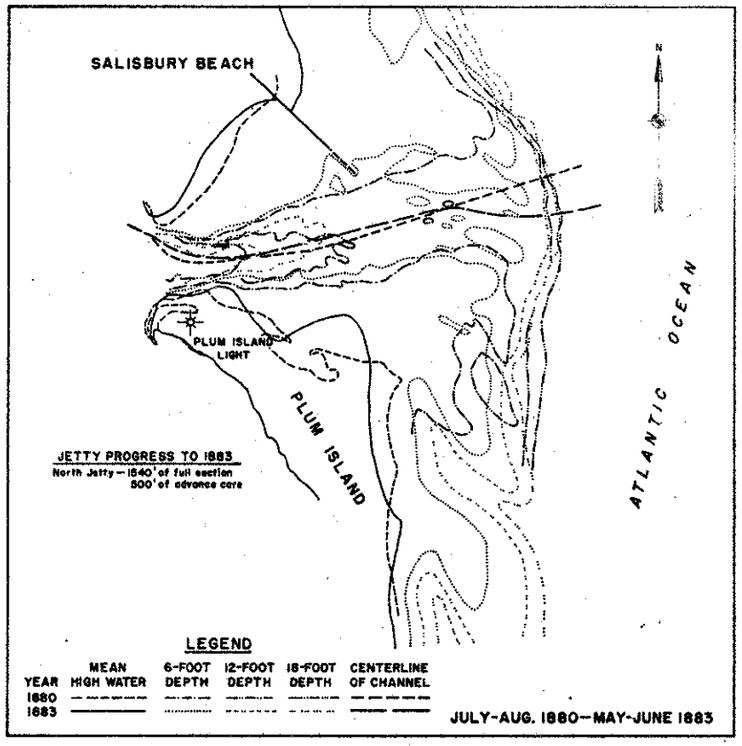
TRANSMITTED WITH REPORT DATED: AUG. 29, 1952

Francis W. Fogarty, CHIEF, RIVER AND HARBOR SECT.

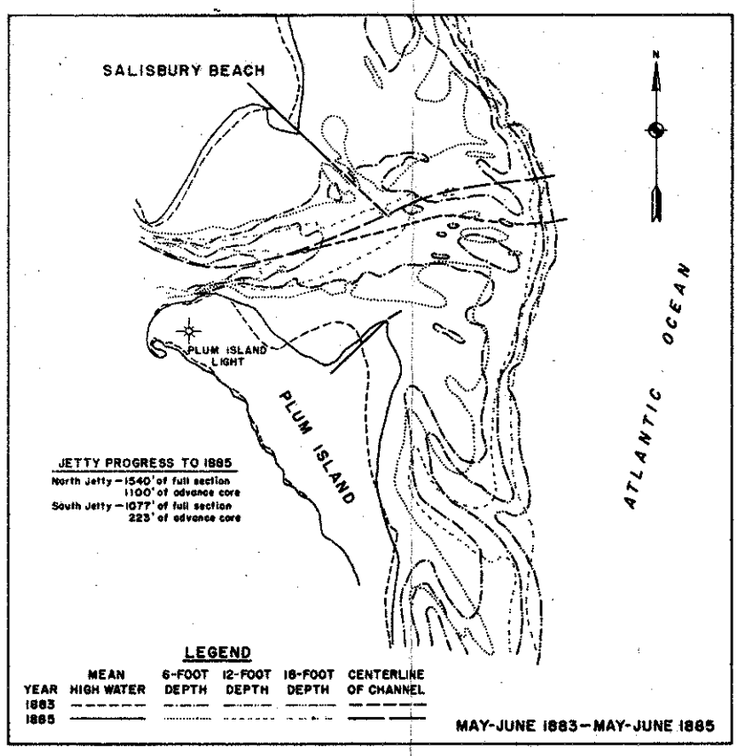
DR. BY I.A.L.D. TR. BY A.L.D. CH. BY JWP

FILE NO. B.E. Pm. Id. 3

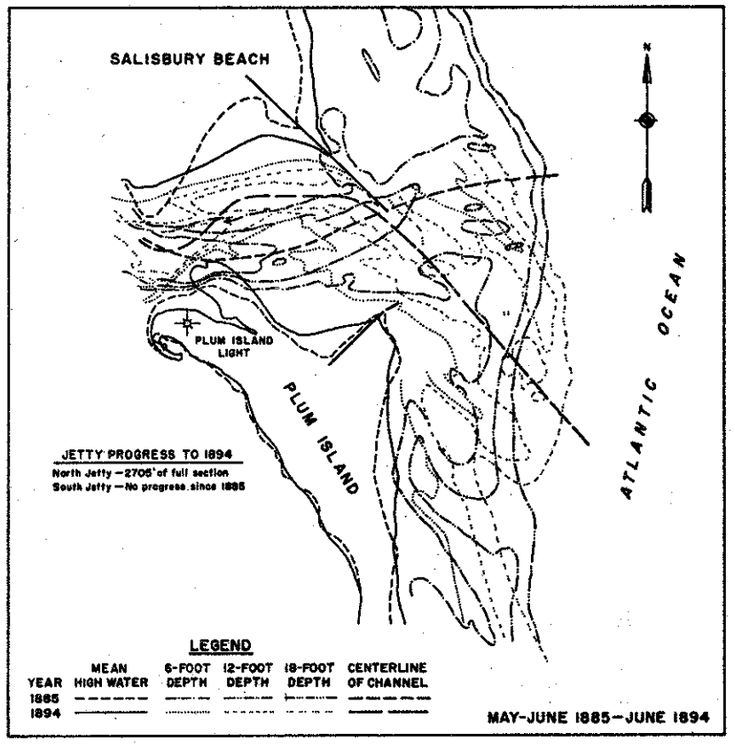
PLATE 5



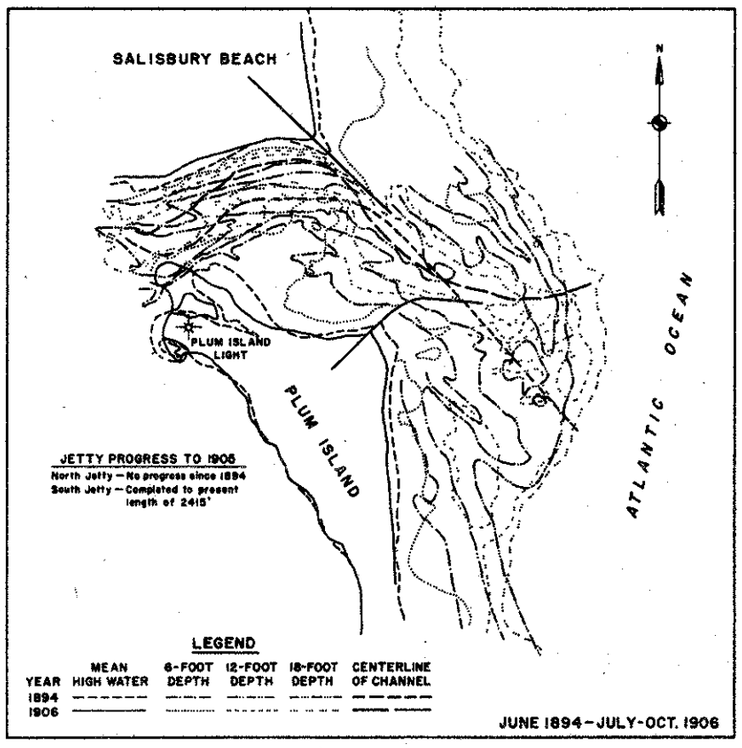
JULY-AUG. 1880–MAY-JUNE 1883



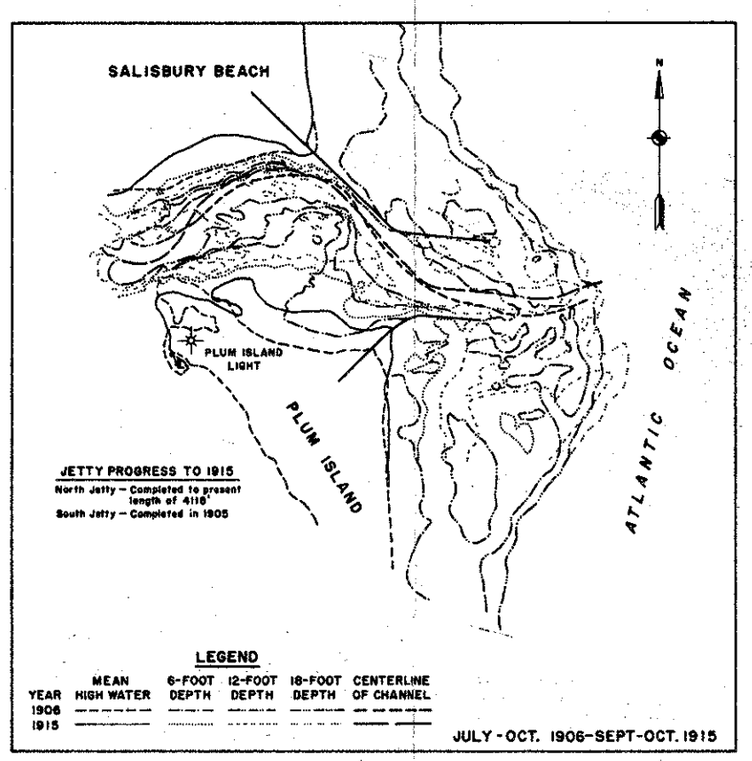
MAY-JUNE 1883–MAY-JUNE 1885



MAY-JUNE 1885–JUNE 1894



JUNE 1894–JULY-OCT. 1906



JULY-OCT. 1906–SEPT-OCT. 1915

NOTES

Depths are referred to the plane of Mean Low Water.

Shore lines and offshore depths are from surveys by the Corps of Engineers, U. S. Army.

BEACH EROSION CONTROL STUDY OF
PLUM ISLAND, MASSACHUSETTS
SHORE LINE & OFFSHORE DEPTH CHANGES
DURING CONSTRUCTION OF JETTIES

IN 1 SHEET SCALE IN FEET 1000 0 1000 2000

NEW ENGLAND DIVISION, BOSTON, MASS. JULY 17, 1952

APPROVED: John G. Allen, CHIEF, ENGINEERING DIVISION
ACCEPTED: COL. C.E. DIVISION ENGINEER
SUBMITTED: CHIEF, PLANNING AND REPORTS BRANCH
TRANSMITTED WITH REPORT DATED: AUG. 29, 1952
CHIEF, RIVER AND HARBOR SECT.
DR. BY I.A.L.D. TR. BY I.A.L.D. CH. BY 360
FILE NO. B.E.Pm. Id. 4

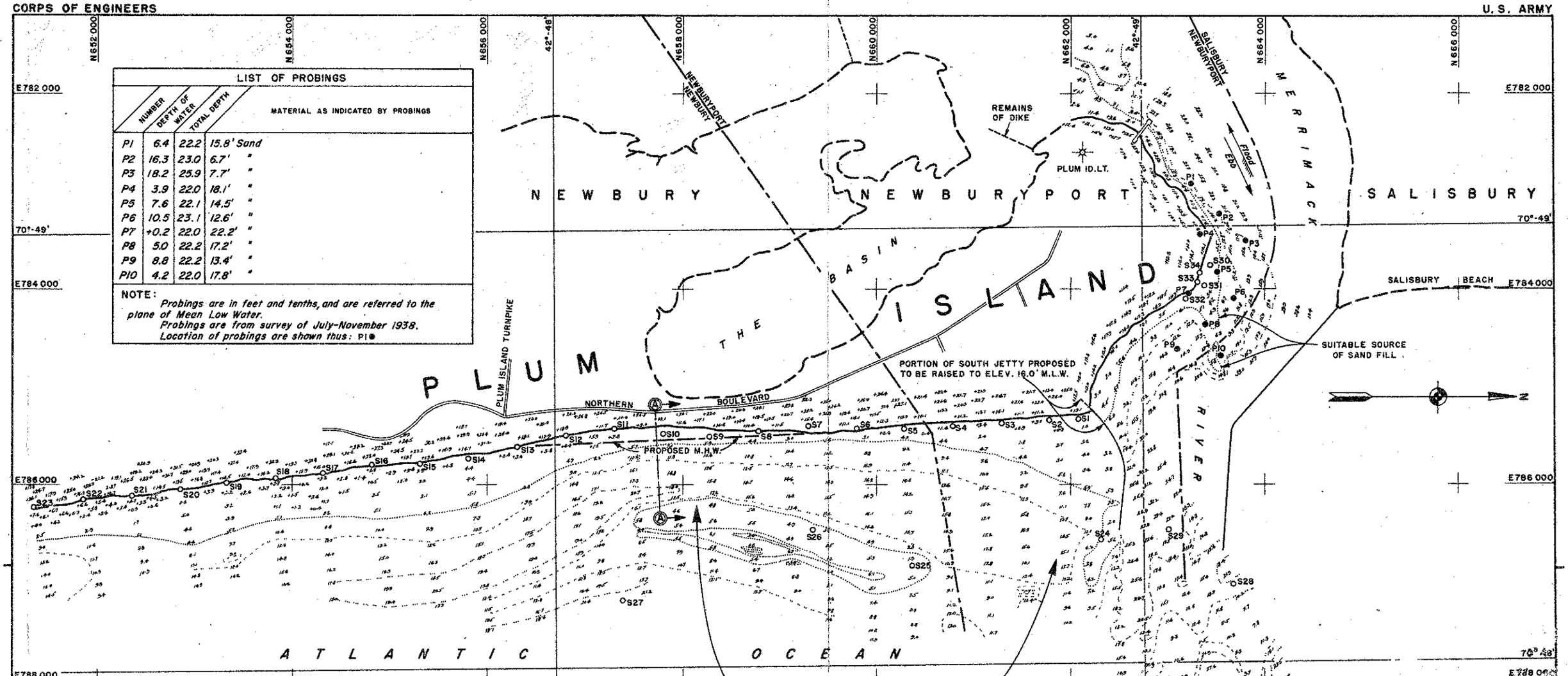
PLATE 6

CORPS OF ENGINEERS — U. S. ARMY

LIST OF PROBINGS

NUMBER	DEPTH OF WATER	TOTAL DEPTH	MATERIAL AS INDICATED BY PROBINGS
P1	6.4	22.2	15.8' Sand
P2	16.3	23.0	6.7' "
P3	18.2	25.9	7.7' "
P4	3.9	22.0	18.1' "
P5	7.6	22.1	14.5' "
P6	10.5	23.1	12.6' "
P7	+0.2	22.0	22.2' "
P8	5.0	22.2	17.2' "
P9	8.8	22.2	13.4' "
P10	4.2	22.0	17.8' "

NOTE:
Probings are in feet and tenths, and are referred to the plane of Mean Low Water.
Probings are from survey of July-November 1938.
Location of probings are shown thus: P1●



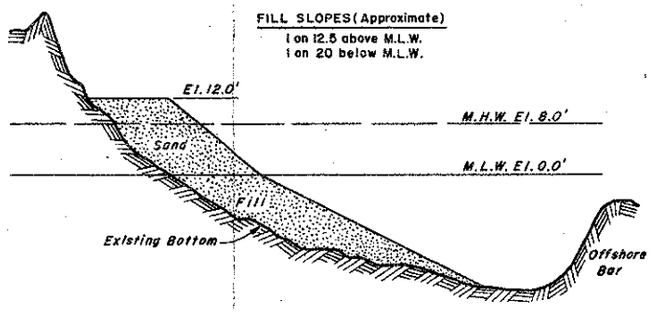
PROPOSED PLAN OF PROTECTION
DIRECT PLACEMENT OF SAND FILL
RAISING OF INSHORE END OF SOUTH JETTY

BEACH SAMPLE ANALYSIS

SAMPLE NUMBER	MEDIAN DIAMETER	CHARACTER OF MATERIAL IN PERCENT				SAMPLE NUMBER	MEDIAN DIAMETER	CHARACTER OF MATERIAL IN PERCENT			
	MILLIMETERS	FINE SAND	MED. SAND	COARSE SAND	GRAVEL		MILLIMETERS	FINE SAND	MED. SAND	COARSE SAND	GRAVEL
S1	0.75	2	98	0	0	S18	0.65	1	99	0	0
S2	0.52	9	91	0	0	S19	0.44	7	93	0	0
S3	0.46	14	86	0	0	S20	0.46	10	90	0	0
S4	0.44	15	85	0	0	S21	0.45	25	75	0	0
S5	0.48	11	89	0	0	S22	0.48	10	90	0	0
S6	0.48	8	91	1	0	S23	0.63	10	88	2	0
S7	0.51	9	87	4	0	S24	1.60	5	67	23	5
S8	0.56	8	90	2	0	S25	1.10	98		2	0
S9	0.42	12	88	0	0	S26	0.80	3	97	0	0
S10	0.47	12	87	1	0	S27	0.95	93		7	0
S11	0.73	3	93	4	0	S28	1.10	99		1	0
S12	0.58	1	98	1	0	S29	0.97	1	92	6	1
S13	0.65	3	96	1	0	S30	0.69	0	99	1	0
S14	0.70	1	98	1	0	S31	0.75	0	98	2	0
S15	0.51	0	100	0	0	S32	0.82	0	98	2	0
S16	0.50	0	100	0	0	S33	0.70	12	87	1	0
S17	0.45	24	74	2	0	S34	0.80	6	93	1	0

NOTE:
Samples were taken during 1952.
Location of samples are shown thus: S10

FILL SLOPES (Approximate)
1 on 12.5 above M.L.W.
1 on 20 below M.L.W.



SECTION A-A
PROPOSED SAND FILL

SCALE IN FEET
HOR. 100 0 100 200 300
VERT. 10 0 10 20 30

NOTES

Soundings and elevations are in feet and tenths and are referred to the plane of Mean Low Water.

Shore line is Mean High Water. The mean tidal range is 8.0 feet.

Soundings, elevations and shore line shown by full line are from survey by Massachusetts Dept. of Public Works during 1952. Jetties and shore line shown by broken lines are from previous surveys.

Plane coordinates are on the Lambert Conformal Conic Projection system for the State of Mass.

Depth contours are shown thus:
6-foot .....
12-foot - - - - - -
18-foot - . - . - .

BEACH EROSION CONTROL STUDY OF PLUM ISLAND, MASSACHUSETTS

PLAN OF PROTECTION

IN 1 SHEET — SCALE IN FEET 500 0 500 1000

NEW ENGLAND DIVISION, BOSTON, MASS. JULY 24, 1952

APPROVED: John S. Allen, CHIEF, ENGINEERING DIVISION
APPROVED: COL. C.E. DIVISION ENGINEER
SUBMITTED: CHIEF, PLANNING AND REPORTS BRANCH
TRANSMITTED WITH REPORT DATED: AUG. 29, 1952
CHIEF, RIVER AND HARBOR BRT.
DR. BY I.A.L.D. TR. BY I.A.L.D. CK. BY
FILE NO. B.E.Pm.Id. 5

PLATE 7

APPENDIX A

GEOLOGY

(From "The Geology of the Coast of Northeastern Massachusetts" by Newton E. Chute and R. L. Nichols)

1. Glacial and Post Glacial Changes in Level. - The New England Coast is a shore line of submergence. Most of this submergence of the land with respect to the level of the sea occurred during the glacial epoch, within the last 1,500,000 years when a series of ice sheets repeatedly advanced and retreated over the area. The amount of submergence increased northward from New York City through New England. It has been estimated that the submergence in the vicinity of the Gulf of Maine amounted to at least 1200 feet and that most of the submergence occurred prior to the advance of the last glacier which melted from the coastal region 25,000 to 30,000 years ago. The retreat of the last glacier was accompanied by a gradual rise in the level of the sea as water was returned to it and also by a slower rise in the level of the land as it was released from the ice load which had covered it. The net result for the Ipswich area, located immediately south of Plum Island, was that sea level rose more than 30 feet higher on the land than it occupies today. With continued melting and retreat of the glacier, the land continued to rise at a rate exceeding that of the ocean, resulting in a new stand of the sea 20 feet or more lower with respect to the land than it occupies today. This lowest stand of the sea is believed to have occurred 10,000 to 15,000 years ago. Since then, sea level has risen to its present position. This last rise in sea level or submergence of the coast may have ceased 3,000 to 5,000 years ago since which time the position of the land relative to the sea has remained essentially stable.

2. Glacial Deposits. - Material picked up and transported by the glaciers and deposited when they melted and retreated from the area are the chief sources of sand in the New England beaches. The glacial deposits

are described as till and outwash. Till deposits are those laid down directly either under the ice or dropped from the ice when it melted. Till is unsorted, unconsolidated heterogeneous material ranging in size from boulders to clay and it is sometimes called boulder clay. Outwash is material which in the process of deposition was acted upon by streams of glacial melt waters. Outwash is, therefore, more or less stratified gravel, sand and silt. The only glacial deposits on Plum Island are small. They are found at its southeast tip and consist of both till and outwash. The till deposits consist of a boulder pavement marking the site of a completely eroded drumlin, a drumlin one-half consumed by wave erosion and a drumlin surrounded by dunes and marsh which has apparently never been eroded on its seaward side. In addition, there are small patches of till and outwash. The rest of Plum Island consists of beach deposits, the larger part of which are more or less completely covered by dunes.

3. Origin of Beach. - Plum Island is a barrier beach. It owes its formation principally to the action of waves which threw up material from the ocean bottom creating bars which retreated landward to form the existing island. The deposits of till, outwash and clay on Plum Island are too small to have yielded enough material to form the beach and dunes. The conditions leading to the formation of the barrier beach were favorable. The deposition of clay, outwash sands and gravels and materials brought down by the Merrimack River obliterated the irregularities in the bedrock surface offshore, thereby forming a gentle, regular seaward slope. Glacial deposits were probably the principal source of sand. Due to this gentle slope, waves broke at a considerable distance offshore, moving sand shoreward and forming ridges parallel to the shore. Continued additions to the ridges or sand bars resulted in the formation of a barrier beach separated from the mainland by a lagoon. This barrier beach migrated landwards as wave action threw and wind action blew material from its seaward side onto its lagoonal side. The width of Plum Island was effected by landward

extension of the sand dunes out over the marsh behind it and also by prograding of the shore after the barrier beach had retrograded landward to its approximate present position. Material may also have been contributed to Plum Island by littoral drifting from adjacent shores. Existing evidence indicates that such drifting is moderate, with only a slight predominance in a southward direction. The absence of any large amount of accretion at the updrift side of existing jetties at the mouth of Hampton and Merrimack Rivers and corresponding erosion on the downdrift side as might be expected if there were one predominant direction of drift indicates that no large predominance exists. A general southward drift of beach sands is indicated by the greater accumulation of beach and dune sands in the southern part of Plum Island and at Castle Neck and Coffin Beaches located south of Plum Island.

4. Shore Forms. - The only noteworthy shore form within the study area is the eastern prong at the north end of Plum Island east of "The Basin". This prong formed as a sand spit which grew northward from the main portion of the island starting sometime between 1827 and 1851. A detailed description of the shore line changes accompanying formation of the spit is included elsewhere in the report. Formation of the spit has been attributed to northward littoral drifting resulting from the action of wind generated waves during a period when southeast storms were predominant over the generally prevailing northeast storms.

5. Future Trends. - The general tendency of shore currents to move from north to south should result in continued southward movement of eroded material from the north to the south. Retrograding of Boar's Head and beaches located to the north will continue while prograding continues in the Castle Neck region. As the northern area retrogrades, more and more bedrock will be exposed, thereby reducing the supply of material to southern beaches. Hampton Seabrook, and Salisbury Beaches and Plum Island will also retrograde, a process which should continue for hundreds of years. Eventually, as the supply of material is reduced by exposure of more bedrock, the Castle Hill region will also retrograde. Ultimately, thousands of years from now, the shore line will be far inland of its present position and lined with bedrock cliffs similar to those now found on Cape Ann.

APPENDIX B

COMPOSITION OF BEACHES

1. Available Data. - Sand samples were taken during August 1932 and analyzed for median diameter in connection with prior beach erosion investigations at Hampton, Seabrook and Salisbury Beaches. Median diameters of beach sands along Plum Island, Castle Neck and Coffin Beach are available from "A Textural Study of Certain New England Beaches", a doctorate thesis by Marshall A. Schalk, Harvard University, 1936. In addition, samples of beach sands along the north end of Plum Island were obtained and analyzed for this study during 1952. Samples along Hampton, Seabrook and Salisbury Beaches were taken at high tide level, mid-tide level and at a depth 10 feet below mean low water. Samples by Marshall A. Schalk, along Plum Island, Castle Neck and Coffin Beach were taken at high tide level, low to mid-tide level and at the sand dunes. Locations and results of analysis of samples taken during 1952 are shown on Plate 7. Locations of samples taken prior to 1952 are shown on Plate 1. Probings were made in the Merrimack River entrance north of Plum Island during 1938 and they are shown on Plate 7.

2. Median Diameters - Hampton and Seabrook Beaches. - Median diameters of samples for Hampton and Seabrook Beaches are tabulated below. Samples were taken on the profiles designated by letters from north to south as shown on Plate 1. Samples taken in the Hampton River inlet have been omitted.

Location	MEDIAN DIAMETERS IN MILLIMETERS		
	M.H.W. Level	Half Tide Level	10-Ft. Below M.L.W.
Profile A	0.165	0.203	0.152
" B	0.246	0.178	0.140
" C	0.177	0.406	0.140
" D	0.229	0.279	0.178
" E	0.246	0.279	0.152
" F	0.254	0.457	0.152
" K	0.305	0.267	0.267
" L	0.292	0.241	0.216
" M	0.394	0.381	0.267

3. Median Diameters - Salisbury Beach. - Median diameters of samples for Salisbury Beach are tabulated below. Samples were taken on the profiles designated by stationing from south to north as shown on Plate 1.

Location	MEDIAN DIAMETERS IN MILLIMETERS		
	M.H.W. Level	Half Tide Level	10-Ft. Below M.L.W.
0 ∠ 0	0.533	0.483	0.483
10 ∠ 0	0.546	0.584	0.432
20 ∠ 0	0.445	0.305	0.203
30 ∠ 0	0.483	0.343	0.241
40 ∠ 0	0.406	0.533	0.241
50 ∠ 0	0.546	0.445	0.234
60 ∠ 0	0.429	0.353	0.178
72 ∠ 0	0.483	0.330	0.229
79 ∠ 0	0.343	0.305	0.203
90 ∠ 0	0.279	0.246	0.229
100 ∠ 0	0.279	0.254	0.216
110 ∠ 0	0.279	0.254	0.229
120 ∠ 0	0.305	0.267	0.229
130 ∠ 0	0.279	0.305	0.254
140 ∠ 0	0.330	0.267	0.241
150 ∠ 0	0.279	0.775	0.254
160 ∠ 0	0.254	0.218	0.216
170 ∠ 0	0.254	0.330	0.203
178 ∠ 72	0.279	0.234	0.203

4. Median Diameters - Plum Island, Castle Neck, Coffin Beach. - Median diameters of samples for the Plum Island-Ipswich area are tabulated below. Samples were taken at approximate locations designated by numbers from north to south as shown on Plate 1.

Location	MEDIAN DIAMETERS IN MILLIMETERS		
	M.H.W. Level	Low Water to Half Tide Level	Dune
1	0.690	1.050	-
2	0.635	0.578	-
3	0.530	0.710	-
4	0.705	0.480	-
5	0.517	0.500	0.325
6	0.618	0.346	-
7	0.390	0.324	-
8	-	0.325	-
9	0.368	0.230	-
10	0.270	0.340	0.222
11	0.260	0.240	-
12	0.208	0.230	-
13	-	0.210	-
14	-	0.192	-
15	-	0.192	0.188

5. Average Median Diameters of All Beaches. - Tabulated below are average median diameters for all samples listed above by individual beaches.

Location	(Samples)	AVERAGE MEDIAN DIAMETERS IN MILLIMETERS M.H.W.	Half Tide	Half to Low Tide	L.W. M.L.W.
Hampton Beach	(A-F)	0.221	0.300	-	0.152
Seabrook Beach	(K-M)	0.330	0.297	-	0.249
Salisbury Beach	(0/40 - 178/72)	0.371	0.361	-	0.249
Plum Island	(1-8)	0.584	-	0.538	-
Castle Neck	(9-12)	0.277	-	0.262	-
Coffin Beach	(13-15)	-	-	0.198	-

6. Comparison of Composition of All Beaches. - All beaches for which median diameters are listed above are sandy in composition. The shore along the north end of Plum Island is coarsest in composition. The beaches are progressively finer northward from Plum Island along Salisbury, Seabrook and Hampton Beaches. The composition of the shore of Plum Island is progressively finer from north to south and this change towards finer material continues south and east of Plum Island along Castle Neck and Coffin Beach. Available samples at the high water level indicate that Hampton Beach is finer than other beaches investigated. No samples are available at the high water level at Coffin Beach. Samples taken between the half tide and low tide level at Coffin Beach were finer than those at the half tide level at Hampton Beach, indicating that Coffin Beach may be as fine or finer than Hampton Beach. Samples of offshore material opposite Hampton, Seabrook and Salisbury Beaches were finer than the onshore material. Samples of offshore material in the Merrimack River entrance and opposite the north end of Plum Island were considerably coarser than the onshore material.

APPENDIX C

TIDES

1. General. - The tides at Plum Island are semidiurnal. The mean tidal range at the entrance to the Merrimack River at the north end of the island is 8.0 feet and the spring range is 9.3 feet. The mean tidal range at the entrance to the Ipswich River near the south end of the island is 8.7 feet and the spring range is 9.9 feet.

2. Tidal Observations. - The nearest station to Plum Island for which United States Coast and Geodetic Survey tidal observations covering a long period are available is located at the Portsmouth Navy Yard, Maine. Observations at other locations between the Portsmouth Navy Yard and, or at, Plum Island are of short duration. The locations and approximate lengths of tidal observations at locations from Plum Island to Portsmouth and their distance from the entrance to the Merrimack River are listed below:

Location	Length of Observations	Distance (miles) from Merrimack River
Portsmouth Navy Yard, Maine	18 years	17.4
Isle of Shoals, New Hampshire	3 months	15.2
Hampton Harbor, New Hampshire	5 months	5.3
Merrimack River Entrance, Mass.	1.5 months	0.0

3. Highest Tides. - Comparison was made between all the high tides observed at the Merrimack River entrance between August 15 - 31, 1928, and high tides for the same period at the Portsmouth Navy Yard to determine whether variations from the mean range of tide were comparable. The largest difference between the variations was 0.3 of a foot and this occurred once. The variations showed a difference of 0.2 of a foot 6 times, of 0.1 of a foot 14 times, and were exactly alike 10 times. A similar comparison was made with the Portsmouth Navy Yard observations, using the 16 highest tides observed at Gosport Harbor, Isle of Shoals, for the periods June 1 - July 31, 1928 and September 15 - October 17, 1941, and also using the 26 highest tides at Hampton Harbor for the periods September 4 - 18, 1928 and July 1 - November 31, 1931. The maximum difference between variations from mean

high water in both instances was 0.2 of a foot and this maximum occurred two times at each location. Differences in variations of 0.1 of a foot occurred 6 times at the Isle of Shoals and 15 times at Hampton Harbor. All other variations were exactly alike. The excellent agreement between the variations in tidal heights from the planes of mean high water at each location indicates that tides at the Portsmouth Navy Yard are typical of those along this entire area. The frequency of occurrence of tides 1, 2, 3 and 3.5 feet or more above the plane of mean high water was determined from the daily high water observations for the years 1927 - 1934, 1941, and 1943 - 1951 at the Portsmouth Navy Yard. It was found that tides exceeded the plane of mean high water by 1 foot or more on an average annual basis 107 times, by 2 feet or more 12 times, by 3 feet or more 0.45 times, and by 3.5 feet or more 0.17 times. The highest tide exceeded the plane of mean high water by 3.9 feet on November 30, 1944. A summary showing the total number of occurrences and the amount of excess for all tides which exceeded the mean height by at least 2 feet for the entire period of record (17.7 years) is given below.

Tides Exceeding Mean Height at Portsmouth Navy Yard, Maine

Feet in Excess of M. H. W.	No. Occurrences	Feet in Excess of M. H. W.	No. Occurrences
2.0	52	3.0	2
2.1	42	3.1	1
2.2	40	3.2	1
2.3	18	3.3	2
2.4	18	3.4	0
2.5	14	3.5	1
2.6	10	3.6	1
2.7	3	3.7	0
2.8	2	3.8	0
2.9	5	3.9	1

APPENDIX D

CURRENTS

1. In the Merrimack River Entrance. - Current measurements in the Merrimack River entrance were made on November 1, 4 and 5, 1937. All measurements were made on the ebb tide. They covered the entire area between the parallel portions of the jetties and more than one-half the northern area of the river south of the inshore arm of the north jetty. The height of the tide above mean low water, the general location, and the maximum currents are tabulated below. All locations are between the jetties.

Date	Height of Tide (Feet)	Location	Maximum Current (Feet/Second)
November 1, 1937	2.6	Mid-channel	5.4
	1.7	350' south of north jetty	6.5
	1.2	250' south of north jetty	5.2
November 4, 1937	5.3	Mid-channel	5.2
	5.3	360' north of south jetty	6.2
	4.2	150' north of south jetty	6.2
	3.6	25' south of bend in north jetty	6.2
	3.4	300' south of bend in north jetty	5.5
	1.9	Mid-channel	5.5
November 5, 1937	3.8	Mid-channel	5.3
	3.1	100' south of bend in north jetty	6.0
	2.2	50' south of bend in north jetty	6.5

The mean currents at maximum ebb and flood computed from mean cubature during 1938 are as tabulated below.

At South Jetty

Fresh water flow 4,660 c.f.s.
Tidal range 9.13 feet
Tidal prism 23,637 acre feet
Maximum flood current 2.58 feet per second
Maximum ebb current 3.23 feet per second

At Coast Guard Marine Railway (N.W. Cor. Plum Island)

Fresh water flow 4,660 c.f.s.
Tidal range 8.5 feet
Tidal prism 22,546 acre feet
Maximum flood current 1.83 feet per second
Maximum ebb current 2.13 feet per second

2. North of North Jetty. - Current measurements were made opposite Salisbury Beach, north of the North Jetty during October and November 1931. Wooden floats made of 2-inch by 4-inch spruce having lengths of 4, 8, 12 and 16 feet were used. The lower ends of floats were weighted so that only 4 inches were out of water. Floats were used in water depths slightly exceeding their lengths. Measured currents averaged 0.07 to 0.40 feet per second, with maximum currents of 0.08 to 0.70 feet per second. The observations indicated that tidal currents on flood tide cause a movement alongshore south towards the mouth of the river and on ebb tide away from the river. The movement during ebb tide is complicated by an eddy current just north of the North Jetty and probably also by reaction currents in addition to wind currents, causing considerable variation in the resulting movement with variation in conditions affecting these factors. None of the observed floats appeared to be affected appreciably by wave action.

APPENDIX E

PREVAILING WINDS AND STORMS

1. Prevailing Winds. - United States Weather Bureau wind records for Boston, Massachusetts, the weather station located nearest to Plum Island, show that prevailing winds approach from westerly directions. Two wind roses made from these records are shown on Plate 1. The wind rose covering the years 1927 - 1937 is based on maximum daily velocities. It shows a very high preponderance of westerly winds with the greatest frequency from a northwest direction. Plum Island faces open water to the east and wave action which can affect the shore can be generated only by winds having easterly components. The frequency of such winds is slightly larger from the east direction and predominantly larger from the northeast quadrant. The wind rose covering the period April 1950 to March 1952 is based on hourly observations of wind speed and direction. This rose also shows a very high preponderance of westerly winds with the greatest duration from the southwest direction. The duration from the northwest quadrant, however, is greater than from the southwest quadrant. Prevailing winds from the easterly directions are shown as having a slightly greater duration from the northeast direction and the northeast quadrant. Wind roses showing average winds in 5-degree squares for the northeastern United States, compiled from records of the United States Navy Hydrographic Office, are also shown on Plate 1. The rose covering the area including Boston and Plum Island shows a high preponderance of winds from westerly directions, and a predominance of winds from the northeast direction and quadrant over other winds having easterly components. It can be concluded from the above that the prevailing winds blow from westerly directions or offshore with respect to the study area, and that winds which blow onshore prevail from the northeast quadrant with no large predominance from any direction in this quadrant.

2. Storm Winds. - A summary of the number of gales compiled from records of the United States Weather Bureau at Boston, Massachusetts,

covering the 75-year period 1870 - 1945, inclusive, is given in the following table.

Gales (1870-1945, inclusive)

Direction	N	NE	E	SE	S	SW	W	NW	Total
No. of Gales	3	80	9	14	12	15	13	14	160
Percent of Total	2	50	6	9	7	09	8	9	100

The above gales represent major disturbances accompanied by high wind speeds of long duration. Classification of direction of each gale was made in accordance with the predominant direction of wind. Variations in direction during gales are not accounted for. From the above, it is apparent that there has been a high preponderance of severe northeast gales.

3. A summary of the number of days when winds of gale force occurred, compiled for the period 1927 - 1937, as shown on the wind rose on Plate 1, is given in the following table.

Winds of Gale Force (41 m.p.h. or greater) 1927 - 1937, inclusive

Direction	N	NE	E	SE	S	SW	W	NW	Total
No. of Days	0	4	2	3	1	5	15	13	43
Percent of Total	0	9	5	7	2	12	35	30	100

The number of days during which the above winds occurred was compiled from records of maximum daily velocities. The compilation does not necessarily represent the number of days on which severe gales occurred since it does not take account of the duration of the high winds. This record indicates that the frequency of occurrence of high winds is greatest from the west and northwest directions and the northwest quadrant, while high winds having easterly components occur most frequently from the northeast direction with little difference in frequency between the northeast and southeast quadrants.

4. A summary of wind speeds and directions compiled from United States Weather Bureau records for Boston for the period April 1950 - March 1952, inclusive, is given in the following table.

Wind Speeds and Directions (April 1950 - March 1952, inclusive)

Wind Speed (M.P.H.)	NUMBER OF HOURS									
Direction	0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	47	Total
N	12	109	365	298	57	30	4	1	0	876
NNE	15	79	233	224	74	23	5	1	0	654
NE	17	167	291	262	120	27	16	5	1	906
ENE	26	108	174	146	74	16	0	1	0	545
E	16	129	314	267	80	18	6	14	1	845
ESE	17	126	320	211	48	22	1	0	4	749
SE	14	125	265	221	39	2	0	0	0	666
SSE	11	137	278	109	26	10	0	0	0	571
S	12	237	308	131	39	13	3	2	0	745
SSW	12	135	295	265	80	16	4	4	0	811
SW	16	287	1102	903	194	45	11	2	0	2560
WSW	9	160	498	296	31	1	0	0	0	995
W	17	203	489	256	33	11	0	0	0	1009
WNW	14	276	930	684	184	53	9	0	0	2150
NW	17	197	666	669	238	108	17	0	0	1912
NNW	9	131	470	576	192	59	5	0	0	1442

The above record shows the winds which have occurred during the recent period when erosion has been particularly severe at Plum Island. The compilation is based on hourly records of wind velocities. The duration of the record is too short to give a reliable indication of wind expectancy. It is interesting to note that this brief compilation which includes duration is in general agreement with the 75-year record of gales discussed above in that winds of gale force (39 miles per hour or greater) occurred predominantly from the northeast quadrant. It is indicated by the above that a high preponderance of the most severe gales which occur at Boston and, therefore, probably at Plum Island, approach onshore from the northeast quadrant and that winds of slightly smaller intensity predominantly blow offshore from the northwest quadrant.

5. Storm Damages. - The following condensed accounts of storm damage at Plum Island, Massachusetts were prepared from storm damage reports, a file of newspaper clippings and a report by the Plum Island Taxpayers Association, all on file in the New England Division Office.

Date	Account
1939-1940	Extensive erosion of the dunes at the north end of Plum Island in front of 8 cottages located about 1/4 mile south of the south jetty at the mouth of the Merrimack River.
February 14 & 19, 1940	Two severe snow storms, the former equalling the worst blizzards on record. Coastal areas were lashed by heavy seas. Heavy surf and extremely high tides accompanied the storms. Damage at Plum Island consisted of erosion and undermining of 2 cottages in the same area as above.
April 21 - 22, 1940	A northeast storm accompanied by extraordinary high tides. About 20 feet of dune washed away at the north end of Plum Island (same area as above) taking with it a cottage and a bulkhead and leaving several other cottages damaged or endangered. Damage estimated at $10,000.
January 12, 1941	Offshore gales during a period of extreme high tides. Dunes eroded along north end of Plum Island in front of 8 cottages (same area as above). Dunes which were 25 to 80 feet wide in front of cottages on April 16, 1940 and had been cut back up to 40 feet on April 21, 1940, had an average width of 20 feet after this storm. Damage to cottages light, estimated at $1,000.
November 1945	Three storms, one from the southeast on November 20, another also southeast on November 22, and the third from the northeast during November 28-30. Storms accompanied by extreme high tides. North of the road leading to Plum Island, the dunes were cut back for distances varying up to 50 feet. Immediately north of the road, 15 cottages were undermined and piazzas and foundations were damaged. Cottages were left in a precarious position at the brink of the eroded dunes. At the south end of the beach, the dunes were cut back about 20 feet and 3 cottages lost porches, steps and skirtings.
February 15 and March 21, 1950	Two northeast storms caused erosion of the beach and up to 15 feet of recession of the sand dunes along the shore north of the road leading to Plum Island in the vicinity of "The Basin".
September 11 - 12, 1950	A northeast storm caused erosion of the beach and up to 30 feet of recession of the dunes along the shore of Plum Island in the vicinity of "The Basin". Three cottages and a garage were totally destroyed, 2 cottages partially destroyed, porches and steps at 10 other cottages were damaged, and the cottages were undermined. Estimated damages to buildings, $25,000.
November 25 - 26, 1950	An easterly storm accompanied by high tides caused erosion of the beach and up to 20 feet of recession of the sand dunes along the shore in the vicinity of "The Basin". The erosion of the dunes undermined cottages located on them. Some cottages were carried out to sea, others battered and destroyed, and other cottages were undermined so that they overhung the beach or were left at the edge of the eroded sand dunes. Estimated damages to buildings was $75,000.

APPENDIX F

SHORE LINE AND OFFSHORE DEPTH CHANGES

1. Basic Data. - Maps showing the location of the shore line and the 6, 12 and 18-foot depth contours of all of Plum Island and portions of adjoining beaches were prepared from United States Coast and Geodetic Survey data for the years 1851-1857, 1878, 1910-1912 and 1928. A survey run by the Department of Public Works of the Commonwealth of Massachusetts during 1952 locating the shore line and offshore depths along the north and east shore of the developed northern portion of Plum Island was added to the above data. In addition, maps were prepared based on selected surveys showing shore line and offshore depth locations at the mouth of the Merrimack River and the north end of Plum Island extending not more than 4500 feet south of the south jetty. The latter surveys cover the period 1827 to 1938 and were mostly run by the Corps of Engineers, United States Army. They show conditions before, during and after construction of the jetties at the river entrance. Maps based on United States Coast and Geodetic Survey data and the 1952 survey by the Commonwealth of Massachusetts are included as Plates 3-4. Maps based on other surveys are included as Plates 5-6. Descriptions of shore line and offshore depth changes for the entire region are presented below based on the U.S.C.&G.S. and the Massachusetts surveys, and separately covering the area in the vicinity of the Merrimack River entrance based on selected surveys. Due to the scales used on available maps, it is obviously difficult to measure small changes with accuracy. Amounts of change, when given in feet, are necessarily scaled distances. The changes described can generally be considered accurate insofar as they indicate the trend in the area described, and approximate only in indicating quantitative changes.

2. Plum Island and Adjoining Shores (1851-1928). - Detailed descriptions covering changes at the Merrimack River entrance, the south end of Salisbury Beach and the north end of Plum Island to the south end of "The Basin" are

included in Paragraphs 8-12. Changes, as shown by comparison of U.S.C.&G.S. surveys, consisted of a large northeastward growth of Plum Island between 1851 and 1912, with the growth continuing at a slower rate in a northward direction between 1912 and 1928. Accompanying this growth of Plum Island, there was a large northwestward retreat of the south shore of Salisbury Beach between 1852 and 1912 which continued at a slower rate between 1912 and 1928. The seaward and river shore of the southeast end of Salisbury Beach, extending about 900 feet west and 2000 feet north of the north jetty, prograded generally less than 100 feet between 1912 and 1928. Recession of the seaward shore of Salisbury Beach, located 2000 to 4500 feet north of the north jetty, occurred between 1912 and 1928, with the maximum recession being about 100 feet. Recession of the seaward shore of Plum Island, located between points 150 to 1800 feet south of the south jetty, also occurred between 1912 and 1928, with a maximum shore retreat of about 100 feet. Recession up to 75 feet also occurred between 1912 and 1928 along approximately 1600 feet of the seaward shore of Plum Island opposite the south end of "The Basin." The seaward shore of Plum Island, located 700 to 5400 feet south of "The Basin," receded between 1852 and 1912 and prograded between 1912 and 1928. The net effect of these changes left this entire shore line, in 1928, seaward of its 1852 position, the largest seaward movement of about 200 feet having occurred at the south end of the area while progressively smaller gains occurred to the north. The seaward shore of Plum Island, located 5400 to 11,100 feet south of "The Basin" prograded between 1852-1854 and 1928, the amount of seaward movement of the shore line varying between 50 and 200 feet. Only the 1854 shore line position of the central portion of the seaward shore of Plum Island is available so determination of changes in this area cannot be made. The seaward shore of Plum Island, located 8800 to 14,800 feet north of the southeast end of the island, prograded about 50 feet between 1853 and 1912 while 5400 feet of shore south of and adjacent to this area receded about 50 feet. During the same period, there was no significant

change in the shore line position at the southeast tip of Plum Island. The southwest end of Plum Island, however, experienced a large growth, the shore line moving 1200 to 1500 feet southward between 1853 and 1912. Large changes also occurred along the Castle Neck shore between 1853-1855 and 1910-1911. Changes consisted of accretion along almost all of the north shore of Castle Neck, the largest shore line movement exceeding 900 feet.

3. Changes in offshore depths in the vicinity of the Merrimack River entrance between 1851 and 1878 were associated with its northward migration. During 1851 there were two natural river channels. One flowed in an east southeast direction about parallel and 200 to 300 feet south of the position of the 1928 shore line of the north end of Plum Island. It then turned and flowed eastward across the outer bar about 600 to 700 feet south of the present position of the outer arm of the south jetty. The other channel flowed further south in a south southeast direction parallel to the 1852 position of the northeast shore line of Plum Island and then turned and flowed in an easterly direction across the outer bar about 3300 feet south of the outer arm of the south jetty. With northward growth of Plum Island and recession of the south end of Salisbury Beach, the main course of the river migrated to the north and in 1878 flowed in a general easterly direction within the area now defined by the outer arms of the north and south jetties. The 6, 12 and 18-foot depth contours which had defined the outer limits of the bar at the mouth of the river in 1851 moved landward after northward migration of the river entrance, the maximum movements of contours up to 1878 being as follows; 18-foot, 1500 feet; 12-foot, 1300 feet; and 6-foot, 1800 feet. As the bar at the 1851 river entrance was eroded, shoaling and formation of another bar occurred at the 1878 river entrance and depth contours moved seaward of their 1851 positions as follows; 18-foot up to 600 feet; 12-foot up to 800 feet; and 6-foot up to 2000 feet. This shoaling extended north of the 1878 river entrance, resulting in seaward movement of

the 6 and 12-foot depth contours opposite the south end of Salisbury Beach while the 18-foot contour moved slightly landward.

4. Offshore depth changes between 1878 and 1928 reflect the effects of construction of the jetties at the river entrance between 1881 and 1914 as well as the continued northward growth of Plum Island and the recession of the south shore of Salisbury Beach. The northward growth of Plum Island was accompanied by growth of a submarine bar from the northwest end of the island. The bar, in 1928, trailed in a northeastward direction across the river entrance toward the shore arm of the north jetty. The river channel was deflected northward close to the south shore of Salisbury Beach and then flowed in a southeasterly direction parallel and very close to the shore arm of the north jetty. It was then deflected by the outer arm of the south jetty and flowed across the outer bar in a direction slightly south of east. Scouring of the river bottom and excessive deepening occurred in the channel close to the shore arm of the north jetty and some deepening also occurred in the channel across the outer bar. The deepening across the outer bar was insufficient to accomplish the original purpose of the jetties which was to create a channel 17 feet deep. The outer bar at the mouth of the river grew in size so that in 1928 the 12 and 18-foot depth contours were up to 1200 feet seaward of their 1878 positions, this seaward movement diminishing gradually for distances about 3000 feet north and south of the river channel, beyond which the contours moved landward. Numerous small 6-foot shoals at the mouth of the river in 1878 did not exist in 1928. The 6-foot depth contours north and south of the jetties moved landward up to 1500 and 1000 feet, respectively, between 1878 and 1928. A large isolated 6-foot shoal existed offshore 1500 to 2500 feet south of the south jetty in 1928. The seaward edge of this shoal was over 1000 feet further offshore than the 1878 location of the 6-foot depth contour. The shoal was oriented in a general northeast-southwest direction parallel to the 12 and 18-foot depth contours.

5. Offshore depth changes opposite approximately 11,000 feet of the Plum Island shore south of "The Basin" between 1851-1857 and 1928 consisted generally of deepening and landward movement of the 6, 12 and 18-foot depth contours. A long 12-foot offshore bar which, in 1857, paralleled the shore, located 5000 to 11,000 feet south of "The Basin" was not shown in 1928, its loss probably resulting from landward movement and connection to the foreshore slope of the island. Offshore depth contours available for the remainder of the seaward shore of Plum Island to the south cover only the period 1851-1857. It is, therefore, not possible to make a comparative study of offshore depth changes for this area. It is interesting to note that in 1857 long, narrow 6 and 12-foot offshore bars existed parallel to most of this shore. The existence of these bars lends support to the theory which attributes formation of Plum Island to wave action throwing up bottom material to form offshore bars which retreated landward to form the present land mass. There was no significant change in offshore depths at the mouth of the Ipswich River south of Plum Island between 1851-1857 and 1911.

6. Plum Island (1928-1952). - Comparison of the shore line and offshore depths at the north end of Plum Island from surveys by the Commonwealth of Massachusetts during 1952 and the United States Coast and Geodetic Survey during 1928 is shown on Plate 4. This comparison indicates that the principal shore line changes along the river shore of the north end of Plum Island consisted of accretion and northward growth of the island of 600 to 700 feet except for a shore recession of about 150 feet adjacent to the south jetty, and a recession of approximately 300 feet at the northwest tip of the island. Shore line changes along the seaward shore of Plum Island consisted of a recession of about 100 feet adjacent to the south jetty diminishing to a point of no change 2000 feet south of the jetty, thence a small amount of accretion or no change along the next southerly 1400 feet, and shore recession along the shore located 3400 to 11,000 feet south of the jetty. The amount of this latter recession gradually increased southward, being about

150 feet opposite the south end of "The Basin," and about 250 feet at a point midway between "The Basin" and the seaward end of Plum Island Turnpike. At Plum Island Turnpike, the recession was about 100 feet and south of this point along the shore fronting the cottages it averaged about 150 feet. Along approximately 2000 feet of shore south of the cottages, the recession averaged about 200 feet.

7. The submarine bar trailing into the river northeastward from the north end of Plum Island towards the north jetty diminished in width and trailed in a more easterly direction while still projecting about the same distance into the river. There was little change in the position and direction of the river channel between the jetties. The 6 and 12-foot depth foreshore contours opposite 1000 feet of the seaward shore of Plum Island south of the south jetty remained in approximately the same position. These same contours opposite the shore 1000 to 5000 feet south of the south jetty moved landward quite close to the high water shore line, and further south the 6-foot depth contour moved seaward while the 12-foot contour moved landward. A 6-foot bar which existed 1500 to 2500 feet offshore about 1000 to 2500 feet south of the outer arm of the south jetty during 1928 increased in length and width and during 1952 occupied a more southerly position 1000 to 1500 feet offshore, 2000 to 5000 feet south of the outer arm of the south jetty, and a 12-foot offshore bar extended southward from the 6-foot bar. A channel with depths exceeding 18 feet formed between the 12-foot offshore bar and the foreshore slope opposite the island between the seaward end of Plum Island Turnpike and the south end of "The Basin," and this channel extended northward with depths exceeding 12 feet between the 6-foot offshore bar and the foreshore slope from the south end of "The Basin" nearly to the south jetty. The greatest depth increase during this period occurred in the above described channel about midway between Plum Island Turnpike and "The Basin," where the depth increased from about 4 to 20 feet. Depths in the channel shoreward of the 6-foot bar were about the same in 1952 as during 1928.

8. Merrimack River Entrance - Before Construction of Jetties (1827-1880).

The oldest available survey of the Merrimack River entrance was made during 1827. At that time, "The Basin" did not exist. The river entrance was located about one-half mile south of its present position. The north shore of Plum Island was 1300 to 2500 feet south of the centerline of the present position of the outer arm of the south jetty, and the south end of Salisbury Beach extended 300 feet south of the same line or approximately 3000 feet south of its present position. The northwest end of Plum Island had the form of a bar trailing into the Merrimack River in a northwest direction and the southeast end of Salisbury Beach had the form of a bar trailing seaward in a southeasterly direction. The low water depth of the river channel across the outer bar was about 5 feet. Major changes must have occurred in the vicinity of the Merrimack River entrance between 1827 and 1851. Although no surveys are available for any intervening years, the probable changes can be reconstructed by comparison of the 1827 and 1851 surveys. The river entrance must have migrated further south after 1827, resulting in erosion of the northeast end of Plum Island so that its northeast shore was in the approximate position of the present west shore of "The Basin". This migration was probably accompanied by growth of the south end of Salisbury Beach in a southeast direction. Following this southward migration, a sand spit or bar formed and trailed northwestward from the northeast end of Plum Island, thereby enclosing the body of water now known as "The Basin." The spit or bar had a length of over 6000 feet and a width varying between 150 and 500 feet in 1851. The north end of the spit or bar occupied a position about 300 feet south of the present position of the centerline of the outer arm of the south jetty. With northward growth of the spit or bar, the south end of Salisbury Beach retreated about 1700 feet northwest of its 1827 position. Two channels existed across the outer bar at the mouth of the river in 1851. One, with a low water depth of 5 feet, was located about

1700 feet south of the 1827 channel. The other, with a low water depth of 7 feet was located about 900 feet north of the 1827 channel. After 1851, the river entrance continued to migrate northward. By 1878, about 600 to 1200 feet of accretion had occurred along the seaward shore of the spit or bar throughout most of its length, the greatest increase in width occurring immediately north of the present narrowest part of the spit or bar. Erosion of the east shore at the root of the spit or bar opposite the south end of "The Basin" occurred during this period. This erosion resulted in a maximum shore retreat of about 300 feet. Combined with the accretion further north, the east shore of Plum Island took on a north-south alignment similar to that which it now possesses. Other shore line changes during this period were loss of about 500 feet of the outer end of the spit or bar and a 300 to 600-foot northwestward retreat of the south end of Salisbury Beach. Two river channels over the outer bar in 1878, with low water depths slightly exceeding 6 feet, were located in positions 750 and 1500 feet north of the 1851 north channel. By 1880, the river channel over the outer bar had migrated 400-500 feet north of the 1878 north channel, it flowed in a slightly more northerly direction and had a low water depth of 7.5 feet. The easterly 1000 feet of the north shore of Plum Island grew an additional 300 to 500 feet northward between 1878 and 1880, while varying amounts of shore recession occurred along the north shore of the island west of the accretion area. During this same period, the southeast shore of Salisbury Beach retreated up to 200 feet northwestward while the most southerly point of the beach prograded slightly southward. The east shore of the north end of Plum Island experienced irregular changes between 1878 and 1880, consisting alternately of erosion and accretion.

9. Merrimack River Entrance During Construction of Jetties (1880-1915). Descriptions of changes are given in tabular form below. Changes are described covering periods when progressive construction of each jetty was

carried on. The seaward shore of Salisbury Beach or Plum Island refers to the shore extending north of the north jetty or south of the south jetty. The river shore refers to the shore extending westward inside the jetties.

Period - August 1880 to June 1883

Jetty Progress. - North jetty started. Constructed to a total length of 2040 feet, of which outer 500 feet was advance core.

Shore Line Changes.

Seaward Shore of Salisbury Beach. - Accretion of 325 feet adjacent to the jetty.

River Shore of Salisbury Beach. - No change immediately adjacent to jetty. Recession up to 300 feet along shore 50 to 2350 feet west of jetty.

Seaward Shore of Plum Island. - With northward growth of the east end of Plum Island, there was recession of 250 to 400 feet along the northerly 1900 feet of the 1880 east shore, accretion up to 200 feet along the next southerly 900 feet and recession up to 100 feet along the next southerly 500 feet.

River Shore of Plum Island. - Accretion and northward growth up to 550 feet along the easterly 1600 feet of the north shore of the island, thence alternately erosion and accretion along the remainder of the shore to the west.

Offshore Depth Changes. - A 100 to 150-foot northward movement of 6 and 12-foot foreshore contours bordering Plum Island inside the jetties was accompanied by a similar northward movement of foreshore contours bordering Salisbury Beach and northward movement of the river channel. The channel across the outer bar outside the jetties was deflected from a direction slightly north of east to east. The width of the river channel across the outer bar between the 6-foot depth contours decreased considerably. The 12 and 18-foot depth curves defining the outer bar in the vicinity of the channel remained in the same position, moved seaward 200 to 300 feet further north opposite Salisbury Beach and moved landward further south opposite Plum Island for varying amounts not exceeding 450 feet. The controlling depth in the continuous river channel across the outer bar remained approximately the same.

Period - June 1883 to June 1885

Jetty Progress. - South jetty started. Constructed to a total length of 1300 feet, of which 223 feet was advance core. North jetty advanced by construction of 600 feet of advance core.

Shore Line Changes.

Seaward Shore of Salisbury Beach. - Accretion of 150 feet adjacent to jetty, and 50 to 200 feet along 2100 feet of shore to the north.

River Shore of Salisbury Beach. - Accretion up to 400 feet immediately adjacent to jetty, and recession of 50 to 140 feet along the shore 50 to 2300 feet west of jetty.

Seaward Shore of Plum Island. - Accretion up to 450 feet adjacent to jetty, decreasing to a point of no change 2000 feet south of jetty, thence smaller, irregular changes to the south with accretion of 50 to 100 feet opposite the south end of "The Basin."

River Shore of Plum Island. - Recession up to 550 feet along 1000 feet of shore west of jetty, changing to accretion up to 200 feet along the next westerly 1000 feet of shore, and little change along the remainder of the shore to the west.

Offshore Depth Changes. - The river channel between the jetties increased in depth and followed its most northerly known course across the outer bar in a direction slightly north of east. Changes in shape and size of the outer bar were minor. The controlling depth in the continuous channel across the outer bar increased from about 7.2 feet to 8.6 feet.

Period - June 1885 to June 1894

Jetty Progress. - North jetty extended to a total length of 2705 feet. No work on south jetty.

Shore Line Changes.

Seaward Shore of Salisbury Beach. - Accretion of 150 to 275 feet along 2000 feet of shore north of jetty.

River Shore of Salisbury Beach. - Accretion of 150 to 550 feet along 1600 feet of shore west of jetty. Recession of 400 feet at south end of beach located 1600 to 2400 feet west of jetty.

Seaward Shore of Plum Island. - Irregular changes, alternately erosion and accretion. Minor erosion along 600 feet adjacent to jetty. Thence generally accretion along next southerly 3400 feet with maximum gain of 300 feet and gain of 200 feet opposite the south end of "The Basin."

River Shore of Plum Island. - Irregular accretion up to 350 feet along 2600 feet of shore west of jetty, thence recession up to 300 feet along rest of north shore of island.

Offshore Depth Changes. - Growth of submarine bar inside the jetties about 1000 feet northward from north shore of Plum Island and corresponding movement of river channel towards Salisbury Beach. Channel across outer bar outside the jetties changed direction from slightly north of east to southeast. Position of channel across outer bar at 18-foot depth moved about 3600 feet southward. Outer bar increased in width in vicinity of 1894 channel, moving 12 and 18-foot depth contours seaward up to 500 and 800 feet, respectively. Outer bar decreased in width in vicinity of 1885 channel, moving 12 and 18-foot depth curves landward up to 700 and 600 feet, respectively. South of 1894 channel opposite "The Basin," irregularities in the 6, 12 and 18-foot depth contours were smoothed out and contours retreated landward up to 350, 500 and 550 feet, respectively. Depth of continuous channel across the outer bar increased from about 8.6 feet to about 12.9 feet.

Period - June 1894 to October 1906

Jetty Progress. - South jetty completed to present length of 2415 feet. No work on north jetty.

Shore Line Changes.

Seaward Shore of Salisbury Beach. - Recession of 50 to 150 feet along 1600 feet north of jetty.

River Shore of Salisbury Beach. - Minor recession adjacent to jetty. Recession up to 200 feet along the shore 900 to 2900 feet west of jetty.

Seaward Shore of Plum Island. - Recession of 175 to 250 feet along 400 feet of shore adjacent to jetty, thence recession of 50 to 150 feet along next southerly 3000 feet of shore.

River Shore of Plum Island. - Recession of 50 to 75 feet along 700 feet of shore adjacent to jetty, accretion up to 50 feet along next westerly 450 feet, thence recession up to 300 feet along next westerly 1500 feet of shore and accretion of 500 feet by westward growth of a trailing bar from northwest end of Plum Island.

Offshore Depth Changes. - Existing submarine bar inside the jetties grew about 400 feet northeastward from north shore of Plum Island, resulting in a corresponding movement of the river channel towards Salisbury Beach. Channel across

outer bar outside the jetties deflected from a southeast to an east direction by the south jetty. Position of channel across outer bar at 18-foot depth moved about 1900 feet northward. Outer bar increased in width in the vicinity of the 1906 channel, moving 12 and 18-foot depth contours up to 500 feet seaward, the increase in width diminishing along approximately 4000 feet south and 2000 feet north of the channel. Maximum depth of channel adjacent to the north jetty increased from about 33 to 50 feet. The controlling depth in the continuous channel across the outer bar decreased slightly while the width between 12-foot shoals decreased from about 700 feet to about 100 feet.

Period - October 1906 to October 1915

Jetty Progress. - North jetty completed to present length of 4118 feet. No work on south jetty.

Shore Line Changes.

Seaward Shore of Salisbury Beach. - Minor recession adjacent to jetty.

River Shore of Salisbury Beach. - Practically no change adjacent to jetty. Large recession, up to 400 feet, along shore 250 feet to 2600 feet west of jetty. Minor accretion at southerly tip of beach west of erosion area.

Seaward Shore of Plum Island. - Accretion up to 300 feet adjacent to jetty. Minor changes, principally accretion along shore 600 to 2000 feet south of jetty.

River Shore of Plum Island. - Large accretion, up to 600 feet along 2500 feet of shore west of jetty. Recession up to 200 feet along 700 feet of north shore of island west of accretion area.

Offshore Depth Changes. - Existing submarine bar inside the jetties extending from north end of Plum Island towards Salisbury Beach diminished in size, resulting in a 700-foot southward movement of the 6 and 12-foot depth contours, and a 300-400-foot southward movement of the 18-foot depth contour. Channel across outer bar outside the jetties still followed an easterly course slightly north of its 1906 position. The outer bar, as defined by the 18-foot depth contour, retreated slightly landward both north and south of the channel, and the 12-foot shoals which formerly bordered the north and south sides of the channel diminished greatly in size. The controlling

depth in the continuous channel across the outer bar increased from about 12.3 feet to 16.8 feet, and the channel width between 12-foot shoals increased from 100 feet to 800 feet. The maximum depth in the channel adjacent to the north jetty diminished from about 50 to 38 feet.

10. Merrimack River Entrance After Construction of Jetties (1915-1938). Available surveys run during 1915, 1916, 1921, 1931 and 1938 were limited to the entrance of the Merrimack River and the offshore area extending 1600 to 2000 feet south of the outer arm of the south jetty. Shore line changes shown by these surveys were as follows:

Seaward Shore of Salisbury Beach

1915-1916 - Small amount of accretion adjacent to jetty.
1916-1921 - Accretion of about 100 feet adjacent to jetty.
1921-1931 - Recession of almost 200 feet adjacent to jetty.
1931-1938 - No change adjacent to jetty. Recession up to 100 feet along shore 100 to 800 feet north of jetty.

River Shore of Salisbury Beach

1915-1916 - Generally recession of less than 50 feet along 2200 feet of shore west of jetty.
1916-1921 - Practically no change adjacent to jetty. Accretion up to 100 feet along shore 400 to 1100 feet west of jetty. Recession up to 200 feet along next westerly 2000 feet of shore.
1921-1931 - Recession up to 125 feet along 1000 feet of shore west of jetty. Accretion up to 250 feet along next westerly 1000 feet of shore. Recession up to 200 feet along next westerly 1200 feet of shore.
1931-1938 - No change at jetty. Accretion varying up to 100 feet along 1200 feet of shore west of jetty. Recession varying up to 75 feet along next westerly 1900 feet of shore.

Seaward Shore of Plum Island

1915-1916 - Recession up to 100 feet adjacent to jetty.
1916-1921 - Recession up to 150 feet adjacent to jetty.
1921-1931 - Accretion up to 100 feet adjacent to jetty.
1931-1938 - Accretion up to 150 feet adjacent to jetty.

River Shore of Plum Island

1915-1916 - Recession up to 100 feet along 1300 feet of shore adjacent to jetty. Accretion up to almost 200 feet along next westerly 900 feet of shore, including the northerly tip of the island. Smaller, irregular changes along remainder of north shore of the island.

1916-1921 - Recession up to 400 feet along 1300 feet of shore adjacent to the jetty. Minor changes along the next westerly 700 feet of shore. Accretion up to 250 feet along next westerly 850 feet of shore. Recession of about 100 feet at the northwest tip of the island.

1921-1931 - Accretion along all the north shore of the island except adjacent to the jetty where little change occurred, the maximum accretion of about 250 feet occurred at the most northerly part of the island.

1931-1938 - Accretion along 2300 feet of shore adjacent to jetty with accretion of 100 feet at jetty and up to 350 feet further west. Recession of up to 250 feet at northerly tip of island.

11. Offshore depth changes inside the jetties between Plum Island and Salisbury Beach were as follows; between 1915 and 1916, the 6 and 12-foot depth contours, which defined the shoal extending northward from Plum Island, moved about 200 feet southward and a continuous channel having a least depth of 18 feet formed in a position closer to Plum Island; between 1916 and 1921, the 6, 12 and 18-foot depth contours defining the above shoal moved northward 600 feet, 450 feet and 400 feet, respectively, and the continuous river channel moved northward closer to Salisbury Beach; between 1921 and 1931 the 6 and 12-foot depth contours defining the above shoal moved southward 500 feet and 150 feet, respectively, the 18-foot depth contour moved 150 feet northward, the width of the shoal increased to the northwest and northeast, and the continuous river channel moved closer to Salisbury Beach and the shore arm of the north jetty; between 1931 and 1938 the outer end of the above shoal, as defined by the 6 and 12-foot depth contours, moved slightly westward while still projecting about the same distance into the river from Plum Island. Maximum depths in the river channel along the shore arm of the north jetty were as follows; 38 feet in 1915 and 1916, 40 feet in 1921, 52 feet in 1931 and 45 feet in 1938.

12. There was practically no change in the position and direction of the channel between the outer arms of the jetties between 1915 and 1938. The course of the continuous channel across the outer bar fluctuated in direction from east northeast in 1915, to east in 1916, east southeast in 1921, east in 1931 and east southeast in 1938. Minimum depths in this channel were 16.8 feet in 1915, 13.4 feet in 1916, 11.1 feet in 1921, 13.2 feet in 1931 and 16.6 feet in 1938. The depth of the channel across the outer bar during 1938 reflects the effects of maintenance of the channel by dredging which was initiated during 1937. Depths prior to 1937 were attained by natural processes.

13. The width of the outer bar in the vicinity of the channel as defined by the 18-foot depth contour increased up to 200 feet between 1915 and 1916, and up to 400 feet between 1916 and 1921. Between 1921 and 1931 the bar decreased about 300 feet, and between 1931 and 1938 it increased in width about 400 feet.

APPENDIX G

EXISTING SHORE STRUCTURES

1. General. - The only existing structures along the shore of the study area are two rubblestone jetties at the mouth of the Merrimack River. A timber and stone dike formerly existed across the mouth of "The Basin." The above structures are described below.

2. Authorization. - Construction of the two jetties was authorized by Act of Congress on June 14, 1880 for the purpose of giving the outer entrance channel a permanence in its location and a depth sufficient to meet the present and prospective commerce of Newburyport Harbor and at the same time to make a safe refuge for vessels caught in easterly storms. Changes were made in the projected location, length, and alignment of the jetties following experience with their progressive construction and changes in shore line positions. The existing project provides for two rubblestone jetties, each 15 feet wide on top at elevation 12 feet above mean low water, with slopes of 1 on 2 on the seaward side and 1 on 1 on the river side; one projecting from the north shore 4,118 feet, the other from the south shore 2,445 feet, converging until 1000 feet apart, and then extending seaward parallel to the axis of the channel for a distance of 1000 feet. The defined purpose of the jetties is to create a permanent channel 1000 feet wide and at least 17 feet deep at mean low water. Construction of the dike across the mouth of "The Basin" appears to have been included in the authorized project in 1882 or 1883, upon recommendation of the engineer oficer in charge of construction. The purpose of the dike was to prevent the opening of a new channel at weak and exposed places (presumably by breaching of Plum Island at its narrowest point opposite the southerly end of "The Basin"). The dike consisted of a timber bulkhead of piles and sheeting covered by quarry chips having a total length of 817 feet. The central 394 feet had a height of 5.5 feet above mean low water and sloped shoreward up to an elevation of 12 feet above mean low water. The quarry chips had a top width of 4 feet and side slopes of 1 on 2.

3. Construction of Jetties. - Construction of the north jetty was begun during July 1881 and completed to project dimensions during October 1914. Construction of the south jetty was started during 1883 and completed to project dimensions during October 1905, except for 30 feet of its outer end which has not been built. During construction, the core of the outer portions of the jetties were constructed to less than project dimensions in advance of the completed inshore portions. Progress of the completed inshore section and the advance core are shown in tabular form below. Changes in lengths are listed to represent progress during the fiscal year of the date in the first column.

Date	LENGTH OF JETTY (FEET)					
	NORTH JETTY			SOUTH JETTY		
	Full Section	Advance Core	Total	Full Section	Advance Core	Total
	Construction Started July 1881					
June 1882		1200	1200			
" 1883	1540	500	2040	Construction Started 1883		
Dec. 1883	"	"	"	1077	-	1077
June 1885	1540	1100	2640	1077	223	1300
June 1886	1540	1135	2675	"	"	"
June 1888	1930	745	2675	"	"	"
June 1889	2080	595	2675	"	"	"
June 1890	2200	475	2675	"	"	"
June 1891	2300	375	2675	"	"	"
June 1892	2485	190	2675	"	"	"
June 1893	2510	165	2675	"	"	"
June 1894	2705	-	2705	"	"	"
June 1896	"	-	"	1540	-	1540
Dec. 1897	"	-	"	1790	-	1790
June 1900	"	-	"	2050	-	2050
June 1905	"	-	"	2247	75	2322
Oct. 1905	"	-	"	2415	-	2415
June 1908	2868	-	2868	"	-	"
June 1911	2868	625	3493	"	-	"
June 1912	2868	1250	4118	"	-	"
Oct. 1914	4118	-	4118	"	-	"

Certain variations were introduced into the construction of the inshore end of the south jetty. The inshore 500 feet of this jetty, built during 1883, extending landward from about the high water line, was constructed by

trenching down to a depth of 2 feet above mean high water and driving one row of 6-inch timber sheet piling in the trench down to a depth of 2 feet below mean low water with the top elevation of sheeting 14.5 feet above mean low water. The trench was filled with rubblestone so as to cover the sheet piling up to an elevation of 19 feet above mean low water. This rubblestone was sloped down to the jetty outside the high water shore line on a slope of 1 on 20. This construction is referred to as the shore extension of the south jetty in the annual reports of the Corps of Engineers. The purpose of the extension was to prevent flanking of the inshore end of the south jetty by washing out of sand by action of the sea. Upon completion of construction of the shore extension, it was noted that the action of wind removed sand and lowered the beach landward of its shore end. A structure described as a catch sand was built during the fiscal year 1884, extending 486 feet shoreward of the jetty extension. This structure consisted of two rows of pickets driven into the beach about one foot apart and 2-1/2 feet above beach level. The area between the rows of pickets was filled with sea weed held in place by a wire screen. Short spurs having an aggregate length of 426 feet were constructed in a similar manner perpendicular to the sand catch. During the fiscal year 1885, the main line of the sand catch was increased in length to 572 feet and the aggregate length of the spurs to 606 feet. During fiscal years 1886 and 1887, another sand catch 480 feet long was built shoreward from the inshore end of the jetty extension on a line slightly north of the one previously built. At this time, extensive reconstruction was made to the old sand catch. The new structure and the reconstruction consisted of two rows of wood piles 5 feet high, 5 feet apart, securely united with the intervening space filled with brush weighted with stones. Spurs projected 10 feet at 10-foot intervals on opposite sides of the sand catch.

4. Construction of Dike. - Construction of the dike across the mouth of "The Basin" was started on May 2, 1883. The details of this structure were

as follows; a central core of oak guide piles penetrating 8 feet below sand level and timber sheet piling 6 feet below sand level, extending across the opening of "The Basin" between the high water shore lines with the top of the sheeting in the middle 300 feet of the opening up to a top elevation slightly above mean low water, with horizontal planking above the sheeting in this low 300-foot central opening up to 4 feet above mean low water, the sheeting and the piling then inclosed in a mound of small rubblestone 5.5 feet above mean low water for about 400 feet in its central portion, sloping up to about 12 feet above mean low water at the shore ends of the dike. Construction proceeded satisfactorily until the horizontal planking was put on. The water then forced itself under the central 150 feet of the sheeting, necessitating the removal of the planking above it to control the leak. About 75 feet of the sheeting in the center of the dike was washed out during the Spring of 1884. The hole was filled with sand. The central 150 feet of the dike was never closed, leaving it as a weir with a depth about 2 feet above mean low water. The structure was not maintained and by 1930 its condition was that of ruin.

5. Effects of the Jetties. - Prior to construction of the jetties, the mouth of the Merrimack River was subject to large changes in position. With construction of the jetties, the mouth of the river was fixed in position, thereby reducing the large movements which had previously occurred. Changes in the position and direction of the channel between the jetties and across the bar outside the jetties still continued. Positions of the channel between 1827 and 1938 are shown on Plates 5-6. The earliest known position of the channel across the outer bar in 1827 was about 1600 feet south of the present location of the south jetty. After the above date, the channel apparently moved further south so that in 1851 one of two channels then existing occupied the most southerly known position, about 3200 feet south of the location of the south jetty. During 1857, 1878 and 1880, with northward

growth of Plum Island, channel positions moved successively northward of their 1851 positions. Construction of the north jetty started in 1881. This construction apparently caused the channel to move southward as evidenced by its 1883 position. The inshore end of the south jetty was built during 1883 to 1885 and extension of the north jetty was also in progress during this period. By 1885, the channel had moved to its most northerly known position. This may have been the result of the south jetty construction or it may have been a continuation of the tendency of the river to migrate northward, a process which was in progress prior to the jetty construction. Extension of the north jetty continued intermittently from 1885 to 1894, a period during which no further work was done on the south jetty. The north jetty extension resulted in a progressively greater deflection of the channel towards a southeasterly direction up to 1895 when extension of the south jetty was started. This extension was continued intermittently up to 1905 when the south jetty was completed to its present dimensions. The effect of the south jetty extension was evident in 1897 when the channel had moved considerably northward. Up to 1905, the channel position then fluctuated south and north, apparently with a tendency to follow a southeastward course past the end of the south jetty. Work was resumed on the north jetty in 1908 and continued until its completion in 1914. This last work does not appear to have had any large effect on the channel position or direction. The channel during 1909 and 1911 had generally the same location as during 1905. Between 1912 and 1938, the channel fluctuated, moving north, then south, and in 1938, the last year for which a complete survey of the river entrance is available, it flowed in an east southeast direction across the outer bar outside the jetties. A less complete survey of the river entrance during 1952 indicates that the channel location during 1952 was similar to that of 1938. Concurrently with changes in the course of the channel outside the jetties across the outer bar, certain changes were occurring within the entrance. These consisted

of a northeastward deflection of the channel towards the Salisbury Beach shore by northward growth of the north end of Plum Island, the channel then being deflected in a southeasterly direction parallel and close to the shore arm of the north jetty and then diagonally across the river mouth from the bend of the north jetty towards the outer tip of the south jetty. This diagonal course of the channel is probably largely responsible for the tendency of the channel across the outer bar to follow a southeastward course. The jetties increased the depths across the outer bar but have not accomplished their original purpose which was to create at the outer bar a permanent channel 1000 feet wide and at least 17 feet deep at mean low water. Maintenance of the channel by dredging was found necessary starting in 1937. Scouring has greatly increased the depth of the channel on the river side of the shore arm of the north jetty. Changes also occurred to the shore lines and offshore depths adjacent to the jetties which are described in the section of the report dealing with shore line and offshore depth changes.

6. Effects of the Dike. - The dike resulted in extensive shoaling in "The Basin," reported as 160,000 cubic yards in 1884, 240,000 in two years up to 1885, and 250,000 cubic yards since 1885 up to 1887. Quantities of shoaling were not reported after this date. It was also reported that the beach at the head of "The Basin" separating it from the ocean increased from a width of 150 feet in 1885 to 550 feet in 1887. The dike reduced the danger of a breakthrough, thereby accomplishing its intended purpose.

7. Effects of the Sand Catches. - It was reported in 1885 that the sand catch resulted in raising the beach level 2 feet, and after reconstruction in 1887 there was a 5-foot increase in the beach height.

APPENDIX H

PRIOR REPORTS

1. Original Study of Hampton Beach, New Hampshire. - The original study was initiated on a cooperative basis during March 1931 by application of the State of New Hampshire. The report on the study was made by the Beach Erosion Board on July 15, 1932. The report found that erosion at the south end of Hampton Beach was serious and that there was urgent need for protection in this area. The erosion resulting from migration of the Hampton Harbor inlet was attributed to tidal currents associated with inlet rather than longshore currents. The report recommended -

a. For the protection of the southern end of Hampton Beach, and incidentally for reclaiming land, construction of a jetty at the north side of the inlet and placement of sand fill behind the jetty.

b. For the fixation and improvement of the inlet channel, in addition to the north jetty, construction of a jetty at the south side of the inlet.

During 1934-1935 the State of New Hampshire constructed a series of dikes and jetties to confine the inlet and reclaimed approximately 50 acres of beach north of the north jetty by pumping hydraulic fill from Hampton Harbor. The work accomplished was a modification of the work recommended by the Beach Erosion Board.

2. Continuing Study of Hampton and Seabrook Beaches and Hampton River Harbor, New Hampshire. - Upon application therefor by the State of New Hampshire on August 31, 1938, the study of problems at Hampton and Seabrook Beaches and Hampton River Harbor was continued by the District Engineer. The District Engineer's report was made on April 15, 1942. It was reported that the new jetties and dikes and the sand fill at Hampton Inlet had successfully stabilized the inlet and protected the southern end of Hampton

Beach, that erosion and storm damage was occurring at Hampton Beach in the vicinity of the business center and immediately south thereof and that the harbor had shoaled extensively since the dredging of 1935. The need for protection of Hampton Beach was recognized. No need for protection of Seabrook Beach was found. It was recommended that a seawall be constructed along the business center of Hampton Beach with spur groins extending seaward of the wall and that groins be constructed immediately south of the business center. The State of New Hampshire constructed a new seawall fronting the business center of Hampton Beach and placed revetment along a portion of shore at the south end of the business center during 1946-1947.

3. Beach Erosion Study of Salisbury Beach, Massachusetts. - This study was made under the direction of the Beach Erosion Board on a continuing basis in cooperation with the Commonwealth of Massachusetts. Work was initiated on July 17, 1931 through an application by the Commonwealth of Massachusetts. The report of the Beach Erosion Board was made on August 26, 1941. It was reported that the predominant littoral drift is from north to south, that the supply of sand formerly reaching the beach from the north has been eliminated by construction of shore protection works and jetties and that sand is impounded by the north jetty at the mouth of the Merrimack River. No new protective works were found to be necessary. It was recommended that the north jetty at the Merrimack River be raised and made sand tight to decrease the volume of littoral drift now passing through and over the structure. It was anticipated that erosion of the beaches south of Hampton River would occur in the future, beginning at the north end of Seabrook Beach and progressing southward.

4. Effect of Federal Structures on Adjacent Shore Lines. - A report describing construction and conditions before and after construction of the jetties at the Merrimack River entrance and a dike across the mouth of "The Basin" was prepared by the District Engineer, Boston, Massachusetts, and submitted to the Shore Protection Board on June 7, 1938. Additional data

supplementing this report was submitted on January 6, 1939. The report contained information on shore line and offshore depth changes, beach and bottom materials, slopes of beaches, winds, storms, littoral drift, tides, currents and effects of the above factors. It also contained details of construction methods, dimensions, layout, initial and maintenance costs. It also contained information regarding permeability of structures to sand, accretion or shoaling, erosion or scouring and deterioration of the structures. It was concluded in regard to the jetties that, (1) they had not achieved their original purpose which was "to create at the outer bar a permanent channel 1000 feet wide and at least 17 feet deep at mean low water," (2) the bar continues to form across the entrance outside the jetties with minimum depths of 6 to 11.5 feet at mean low water, and (3) that no economically warranted modification of the jetties would accomplish their original purpose. It was concluded in regard to the dike across "The Basin" that it had fulfilled its purpose by lessening the danger of the sea breaking through and that the basin had silted to a considerable degree.